# WORK OF THE BOARD OF WATER SUPPLY

A GENERAL DESCRIPTION

OF THE

# CATSKILL WATER SUPPLY

AND OF THE

PROJECT FOR AN ADDITIONAL SUPPLY

FROM THE

# DELAWARE RIVER WATERSHED

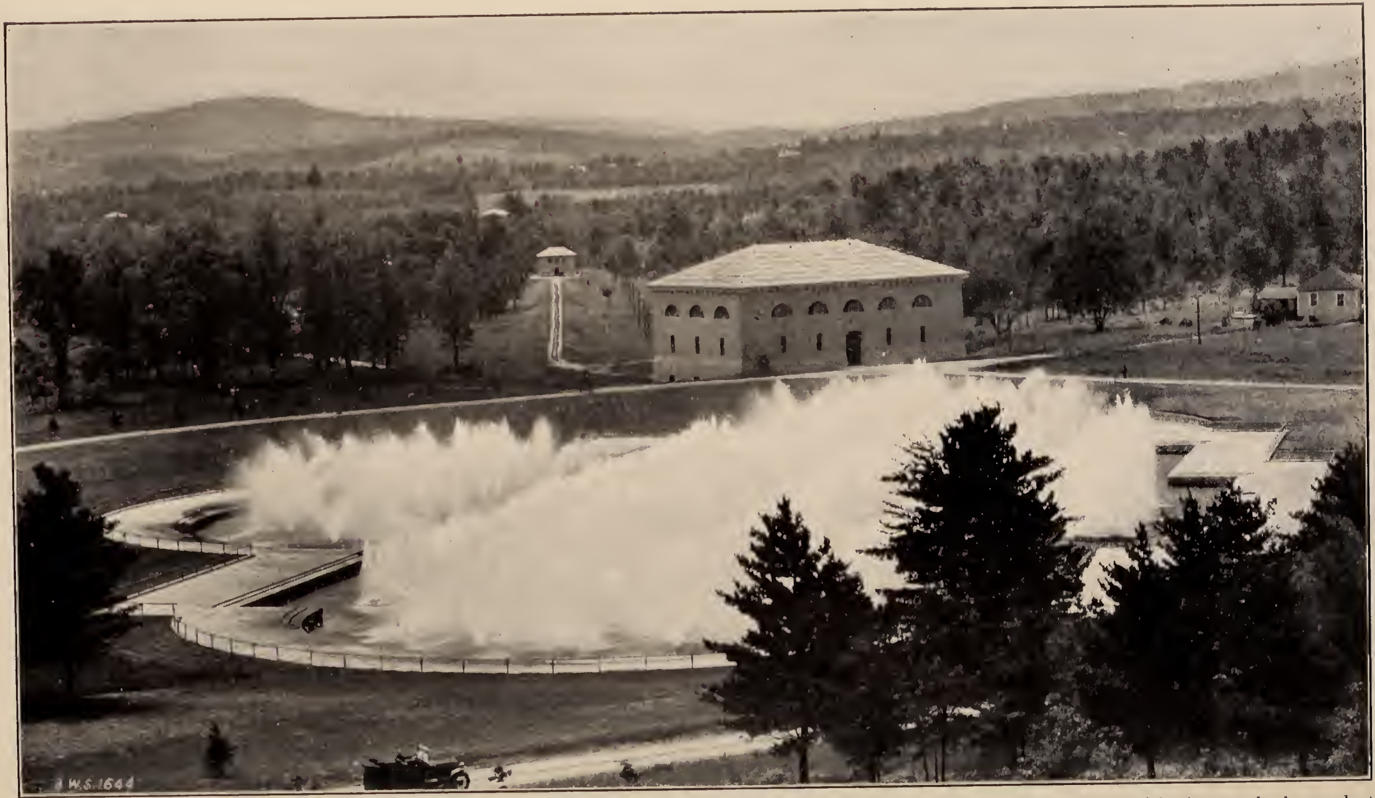
AND THE

# RONDOUT CREEK

BOARD OF WATER SUPPLY

OF THE CITY OF NEW YORK

1936



The Ashokan aerator and the beginning of the Catskill aqueduct. The large building is the Ashokan screen chamber, at which the standard aqueduct begins. Following the aqueduct embankment, one comes first to the Ashokan gaging chamber and, to the left, the two chambers of the Esopus steel-pipe siphon.

# WORK OF THE BOARD OF WATER SUPPLY

## INTRODUCTORY—NEW YORK CITY'S WATER SUPPLY PROBLEM

The Board of Water Supply of the City of New York is charged with the planning and construction of additions to the City's existing water-supply systems. When such additions are completed they are turned over to the Department of Water Supply, Gas and Electricity for maintenance and operation.

Before describing the Catskill Water Works and the present work of the Board of Water Supply, a statement concerning the water-supply situation in New York City as it existed before the creation of the Board will help in appreciating the problem of providing a rapidly growing city with an adequate and wholesome supply of water.

Prior to the year 1898, when the municipalities now within the bounds of New York City were consolidated, these municipalities had already experienced periods of acute shortages in the water supply; after consolidation, one of the most serious problems facing the City was that of providing an adequate water supply, particularly for the Boroughs of Manhattan and Brooklyn. The old City of New York, comprising what is now the Borough of Manhattan and a portion of the Borough of The Bronx, was then obtaining its supply solely from the Croton watershed, which was first used as a source of water for the City in 1842. Williamsbridge, now a part of The Bronx, was served by a pipe-line from the Bronx and Byram rivers. The old City of Brooklyn was supplied by the Ridgewood system from small streams and well stations on the south shore of Long Island in the Counties of Kings, Queens and Nassau. The supplies for the small communities now within the Boroughs of Queens and Richmond were similarly provided from wells and small surface streams. As a result of the overdraft on many of these ground-water sources, the quality of much of the water had deteriorated, owing to local pollution and salt-water infiltration.

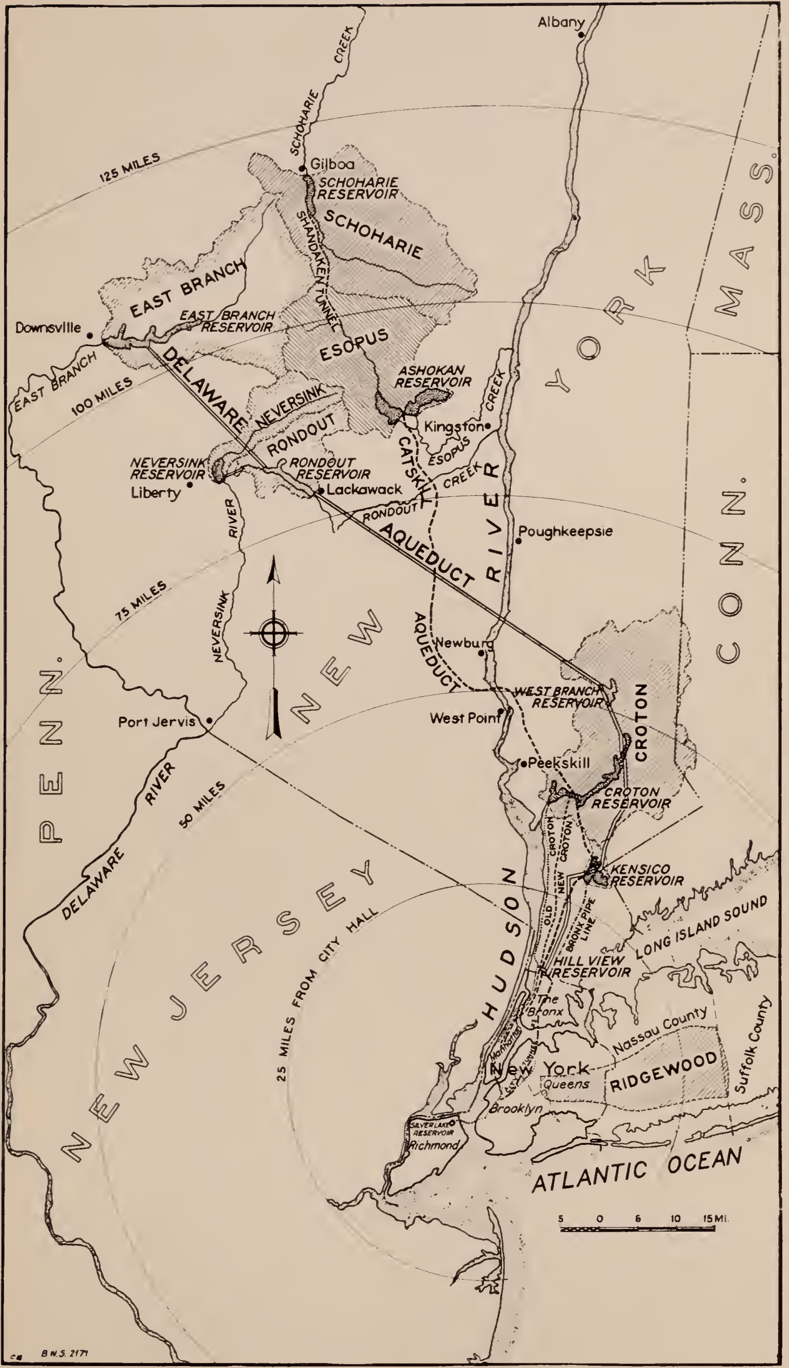
Soon after the consolidation in 1898, it was proposed that a private company should supply the City from the Ramapo river and the Catskill mountains on terms which would presumably have been profitable to the company. This attempted exploitation of the City led Comptroller Bird S. Coler to have a thorough investigation made and, for this purpose, he appointed John R. Freeman, whose report in 1900 set forth the need for an additional supply and pointed out those sources from which it could be obtained. The Ramapo scheme being exposed and the community being roused, various civic organizations became active, especially the Merchants' Association, which, in August 1900, published reports of a number of engineers engaged to conduct independent investigations.

Commissioner of Water Supply Robert Grier Monroe, in December, 1902, appointed William H. Burr, Rudolph Hering and John R. Freeman as a Commission on Additional Water Supply. This commission was charged with the investigation of the needs of the various boroughs of the City, of measures for curtailing waste, and with the duty of recommending the most available sources and the best means of their development. In November 1903, this commission submitted its report, which recommended the development of the Esopus watershed in connection with certain sources of supply lying east of the Hudson river in Dutchess county. The following Legislature, however, enacted laws which prohibited the City from utilizing most of the sources east of the Hudson which had been recommended for development. The commission reported unfavorably on the filtration of water from the Hudson river. In the meantime, the Aqueduct Commissioners were putting forth every effort to develop the Croton watershed as far as practicable, and the Department of Water Supply, Gas and Electricity was doing its best to extend the underground systems in Nassau county. In the immediate background there was ever present the fear that a dangerous shortage of water in the City might at any time occur.

This, in short, was the situation at the end of the year 1904. Eight years had been spent in collecting information and in educating the people and the State and City governments. One very important preliminary step had, however, been taken; in 1904 an amendment to the State Constitution had been ratified, removing capital expenditures for water-works from within the scope of the municipal debt limit. Meanwhile, the population of the Greater City had increased to four millions and was growing at the rate of 115,000 per year. The demand for water was rapidly going ahead of the dependable yields of the supplies available and severe shortages had been imminent on more than one occasion. Under these conditions, the City again appealed to the Legislature and, at the beginning of 1905, the McClellan Bill was introduced. After some vicissitudes, this bill which had the combined backing of the City administration and the civic organizations, became a law by signature of Governor Frank W. Higgins, on June 3, 1905.

In order to safeguard the interests of all communities of the State and to control the utilization of the State's water resources, the Legislature coincidentally passed a companion bill creating a State Water Supply Commission. These bills, approved on the same day, became, respectively, Chapters 724 and 723 of the Laws of 1905. From time to time, as the years passed, these laws were amended and other special legislation was enacted. The duties of the State Water Supply Commission were later merged with those of the Conservation Commission, still later with those of the State Water Control Commission, and more recently with those of the State Water Power and Control Commission. Among the various amendments, New York City was required to create and maintain a special force of constabulary for the protection of the communities in which its construction operations were being carried on. Certain municipalities were given rights to take water from the new aqueduct. Labor laws were made more strict and statutes relating to the liability of employers were enacted. Payment for indirect damage to land and property not actually taken for the needs of the water supply and for the loss of business and wages was provided for. Under these various prescriptions and requirements, the work was rapidly and energetically prosecuted so that by the end of 1917 the first step in the development as a whole was completed and upwards of 250 millions of gallons of Catskill water daily were available for use. From that time on, the system was in fact drawn upon at the rate of 400 million gallons daily until 1924, in which year the second installment of Catskill Mountain water was partially available for use and the draft from this system was increased to over 550 million gallons per day. The Schoharie reservoir was completed in 1926 and the average draft has since continued at approximately 600 million gallons daily.

AVERY
DURST



New York City's water supply, showing the existing Catskill, Croton and Ridgewood systems and the proposed Delaware system.

## ORGANIZATION OF BOARD OF WATER SUPPLY

Chapter 724 of the Laws of 1905 provided that the Board of Water Supply should comprise three Commissioners to be appointed by the Mayor who should have authority to proceed with a water supply project when authorized by the Board of Estimate and Apportionment and approved by the State Water Supply Commission. With this organization continuity of administration and policy in the prosecution of any undertaking was assured, and the City has had a trained organization of administrators and engineers familiar with the City's water problems to call upon at any juncture.

The Board of Water Supply functions through the following bureaus:

Administration bureau, Bureau of Claims, Police bureau, Engineering bureau.

The Administration bureau, now comprising the Secretary's office and the Auditor's office, has charge of the official records, accounts, purchasing of supplies and other matters of general administration.

The Bureau of Claims was organized July 9, 1912. It is charged with the duty of collecting facts relating to claims for indirect damage, claims for damage to established business arising from the creation of the new water system, and many other closely related matters. This bureau coöperates with the Corporation Counsel in the investigation and preparation of cases prior to trial before the commissioners of appraisal.

Until abolished in 1917, the Real Estate bureau was organized to acquire real estate by direct purchase and make adjustments and payment of taxes. These duties have since been taken over by the Administration bureau.

The Police bureau is assigned to the protection of "the inhabitants of the localities in which any work may be constructed under the authority of this act and during the period of construction, against the acts or omissions of persons employed on such works or found in the neighborhood thereof."

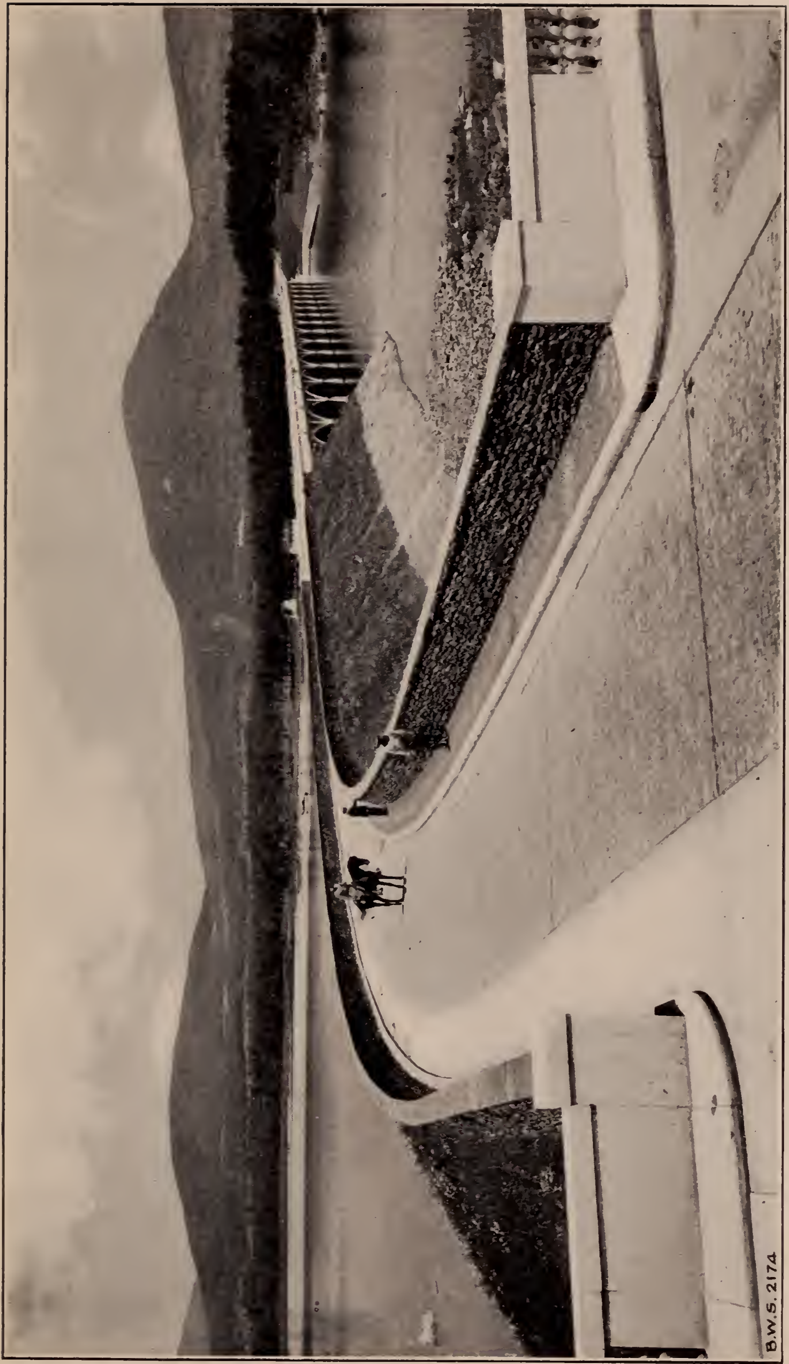
To the Engineering bureau was committed the duty of making all surveys and investigations, the preparation of estimates, designs, contracts and reports, the inspection and test of supplies, equipment and materials, the supervision of construction and of all other engineering matters relating to the project as a whole. This bureau is divided into departments, which are again divided into divisions and sections, the department engineers reporting directly to the Chief Engineer.

Unlike other City departments, the number of men employed in the several bureaus fluctuated widely, being built up to supervise each project and decreased as such work was finished. The maximum number was employed on June 21, 1911, when there were 1,757.

### Personnel

On June 9, 1905, Mayor George B. McClellan appointed as members of the Board of Water Supply, J. Edward Simmons, who was elected President, Charles N. Chadwick and Charles A. Shaw. These Commissioners saw the Catskill system well under way and were replaced one by one by others as vacancies occurred through death and voluntary resignation. The present members of the Board are George J. Gillespie, President, and Henry Hesterberg, there being one vacancy.

The Commissioners who have served on the Board of Water Supply during the past 30 years and their terms of office have been as follows:



The Ashokan reservoir, showing the dividing weir dike, the Ashokan bridge and portions of the east and west basins of the reservoir.

| | |
|---|---|
| J. Edward Simmons | June 9, 1905 to January 28, 1908 |
| Charles N. Chadwick | June 9, 1905 to October 23, 1920 |
| Charles A. Shaw | June 9, 1905 to January 12, 1911 |
| John A. Bensel | January 31, 1908 to December 31, 1910 |
| John F. Galvin | January 23, 1911 to April 27, 1920 |
| Charles Strauss | February 7, 1911 to March 19, 1918 |
| L. J. O'Reilly | April 23, 1918 to February 1, 1922 |
| George J. Gillespie | April 28, 1920 to date |
| James P. Sinnott | November 1, 1920 to September 10, 1928 |
| Philip F. Donohue | April 4, 1922 to July 31, 1934 |
| William F. Delaney | November 21, 1928 to August 24, 1933 |
| Henry Hesterberg | December 12, 1933 to date |

There have been six secretaries since the Board of Water Supply was organized, as follows:

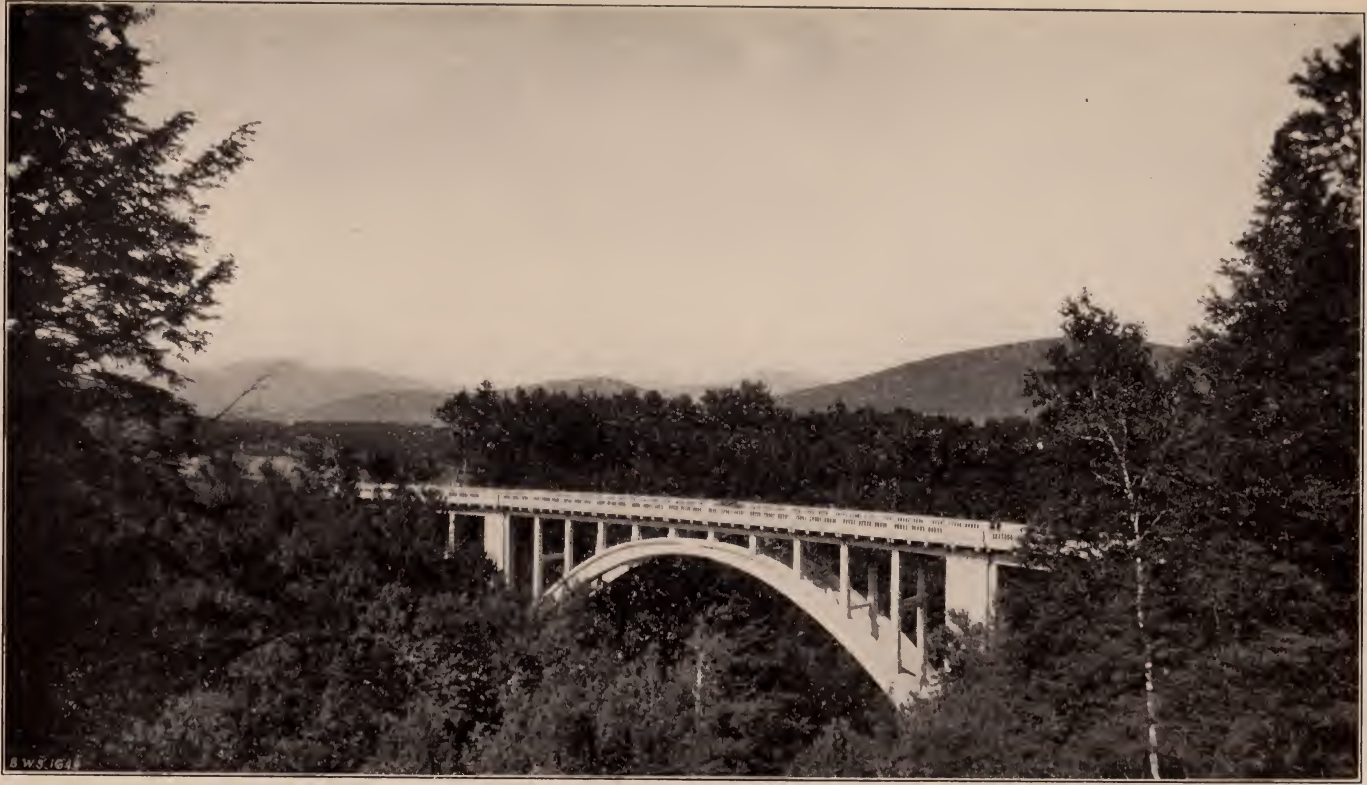
| | |
|---|---|
| Thomas Hassett | December 13, 1905 to January 14, 1910 |
| Thomas H. Keogh | January 15, 1910 to December 31, 1910 |
| Joseph P. Morrissey | January 1, 1911 to February 16, 1914 |
| W. Bruce Cobb | February 17, 1914 to July 9, 1915 |
| George Featherstone | September 13, 1915 to March 9, 1918 |
| Benjamin F. Einbigler | March 19, 1918 to February 29, 1936 |

Henry C. Buncke became Auditor of the Board on August 1, 1905, shortly after the Board was created, and continued in that position until he retired on July 31, 1934. He was succeeded by John M. Carroll, as Acting Auditor.

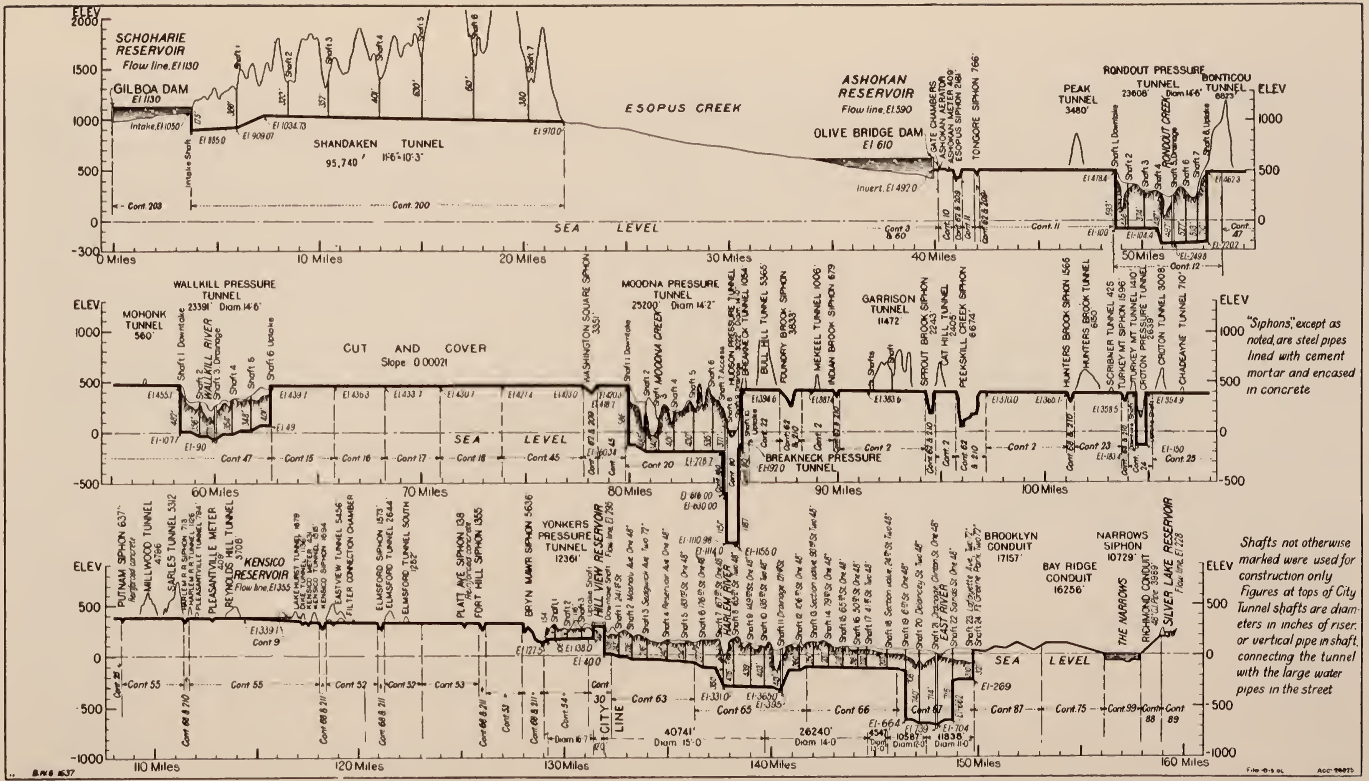
The Engineering bureau was in charge of J. Waldo Smith, as Chief Engineer, from August 1, 1905 until his resignation on May 31, 1922, when he was appointed Consulting Engineer. He served in this capacity until the day of his death on October 14, 1933. It was under his direction that the plan of the Catskill Water Supply was conceived and ably prosecuted. The Catskill Water Supply System will forever remain a monument to his genius, courage and high integrity.

Thaddeus Merriman succeeded J. Waldo Smith as Chief Engineer. He was directly responsible for the plans and construction of the Schoharie development. Through his efforts, the City of New York obtained a favorable decision from the Supreme Court of the United States regarding its right to a share of the waters of the tributaries of the Delaware river. Mr. Merriman retired on November 29, 1933, and was succeeded by Walter E. Spear, as Acting Chief Engineer.

To aid the engineers with their work, the Board employed outstanding men in the engineering profession as consultants. John R. Freeman and William H. Burr served as Consulting Engineers from the inception of the Catskill system until their deaths, the first on October 6, 1932, the second on December 13, 1934. Alfred Noble and Frederic P. Stearns also belonged to the consulting staff during the early days of the work, the one from September 16, 1909 to April 19, 1914, the other from August 1, 1905 to December 1, 1919. From July 2, 1906 until his death, George W. Fuller was consulted from time to time on sanitary matters. Dr. Charles P. Berkey, who had been an occasional consultant since August 27, 1906, joined the staff of the Board on September 14, 1921, and still remains as Consulting Geologist. York and Sawyer have been Consulting Architects.



The Traver Hollow bridge over a small stream entering the west basin of the Ashokan reservoir; the bridge is of reinforced concrete with a 200-foot, three-hinged arch. This is one of sixteen highway bridges built in developing the Catskill water-supply system.



"Siphons," except as noted, are steel pipes lined with cement mortar and encased in concrete

Shafts not otherwise marked were used for construction only. Figures at tops of City Tunnel shafts are diameters in inches of riser or vertical pipe in shaft connecting the tunnel with the large water pipes in the street

Profile of the Catskill water-supply system from the Gilboa dam to the Silver Lake terminal reservoir, showing the elevations of the reservoirs and of the different parts of the aqueduct.

## THE CATSKILL WATER SYSTEM

The Catskill Water System, one of the largest of the world's great public works, was constructed in two stages. The first stage, comprising the impounding of the Esopus watershed and the construction of the Catskill aqueduct of sufficient capacity to carry the Esopus supply to the City, was begun in 1907, about two years after the organization of the Board, and was finished in 1917, just in time to prevent a serious water shortage. The second stage, comprising the extension of the system to divert the Schoharie creek into the Esopus creek and the completion of the Catskill aqueduct to its full capacity, was started in 1917 in anticipation of the early need of more water than could be obtained from the Esopus creek, and was so far completed in 1924 that the natural flow of the Schoharie creek could be diverted to the Esopus creek; the project was finally completed in 1927 when the Gilboa dam was closed and the Schoharie reservoir filled.

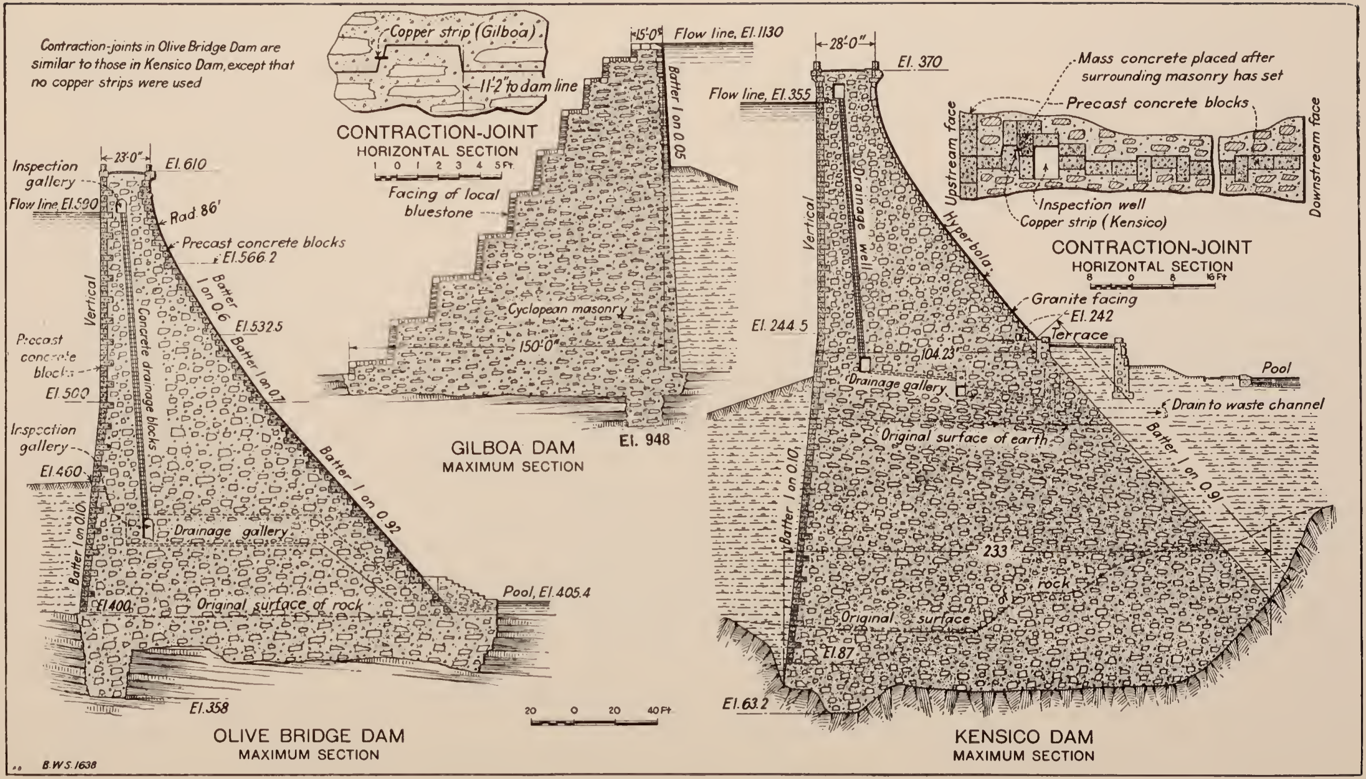
A second delivery tunnel, known as City Tunnel No. 2, was started in 1928 and is now completed. It is 20 miles long and extends from the Hill View reservoir through the Boroughs of The Bronx, Queens and Brooklyn.

Water from the Catskill sources flows to, and is delivered within, the City by gravity. That is to say, the water flows from the Ashokan reservoir to the City and into the distribution pipes under such pressure that, except for the highest services, it need not be pumped before it reaches the people who use it. In this respect, Catskill water has to an extent rendered unnecessary the pumping which was formerly done to the higher services in Brooklyn and much of that in Manhattan, The Bronx and Richmond.

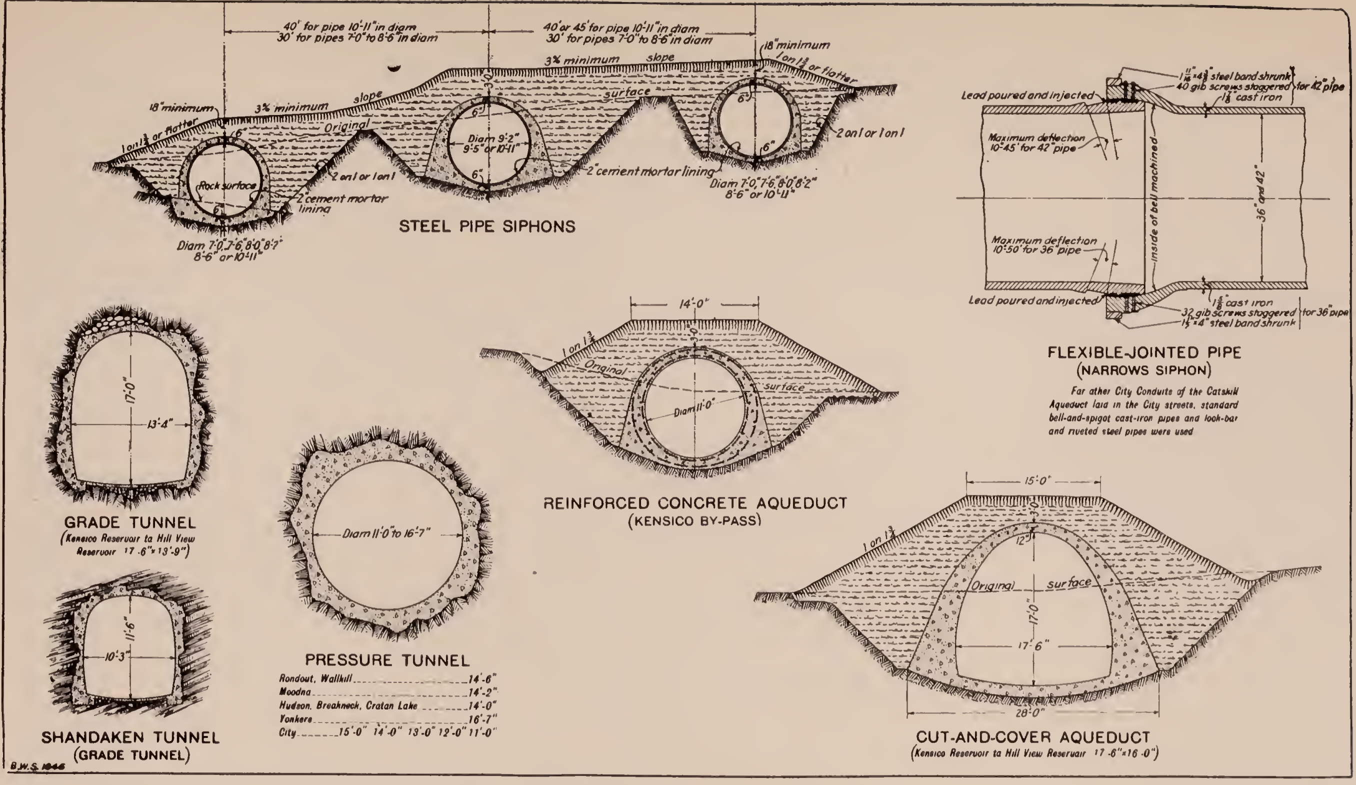
### The Esopus Creek Development

The Esopus creek, a tributary of the Hudson river, drains the central and higher portions of the Catskill mountains in the Counties of Greene and Ulster. These mountains rise to elevations of 3,500 to 4,200 feet above sea level on the northerly and southwesterly borders of the drainage area and are all heavily forested. Including a portion of the original Beaver Kill watershed diverted into the Esopus watershed by the dikes of the East basin of the Ashokan reservoir, the total drainage area of the Esopus creek above the main dam on that creek at Olive Bridge, about 11 miles west from the City of Kingston, is 257 square miles. Upon the completion of the Ashokan reservoir and the Catskill aqueduct, a first supply for New York City of upwards of 250 million gallons per day became available.

*The Ashokan Reservoir.*—The Ashokan reservoir, an artificial lake about 12 miles long, is located from about 6 to 15 miles westerly from the City of Kingston, in the broad valley of the Esopus creek above the Olive Bridge dam and in the adjacent Beaver Kill valley. This reservoir has a water surface of 8,180 acres, equivalent in area to that of Manhattan below 110th street, and an available capacity of 128 billions of gallons, a quantity sufficiently great to cover all of Manhattan Island to a depth of 30 feet, and was designed to equalize the flow from tributary watersheds as well as that of Esopus creek. The principal structures which form the reservoir are the Olive Bridge dam, 4,650 feet long and 252 feet high, built of masonry across the Esopus creek, the earth dikes or dams with concrete core-walls which close the gaps between the hills forming the natural walls of the reservoir, the dividing dike and weir of earth and masonry which separate the reservoir into the east and



Cross-sections of the principal masonry dams of the Catskill water-supply system. Flood waters flow over the top of the Gilboa dam but not over the Olive Bridge nor the Kensico dam.



Standard types of conduit used in the Catskill aqueduct. (In addition to the above, riveted and lock-bar joint steel pipes and bell-and-spigot cast-iron pipes of ordinary types were used.)

west basins, and the waste weir in the east basin over which the surplus flood waters may be discharged into the Esopus creek below the Olive Bridge dam. The total length of all these structures is 5½ miles. The full water surface elevation of the west basin is 590 feet above mean tide at New York, that of the east basin three feet lower. This division into two basins was made so as to provide greater flexibility of operation and thus at all times insure the drawing of water from that part of the reservoir in which the quality of the water is best. Water from the reservoir, after being drawn through gates which are operated by electric power generated by the head of water in the reservoir passes through 1,599 nozzles in the aeration basin. These nozzles break up the water into a fine spray and thus permit any odor-producing gases which may be contained in the water to escape.

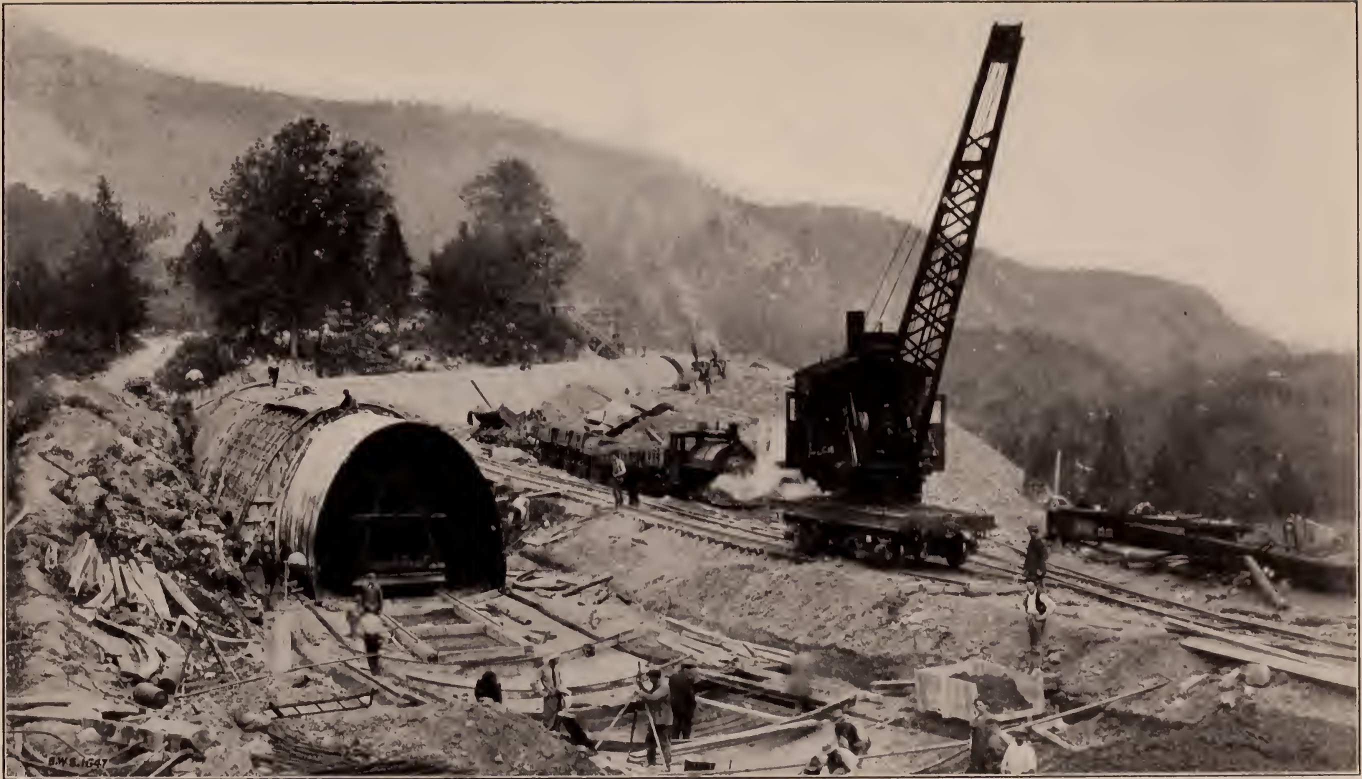
The masonry portion of the Olive Bridge dam is founded on solid ledge-rock and was built of cyclopean concrete faced with smoothly finished concrete blocks. At each end, the masonry section is flanked by earth dikes with concrete core-walls which were built of selected earth which was spread in thin layers and thoroughly compacted by rolling. Before filling, the bottoms and slopes of the reservoir basins were cleared of trees, brush and all other objectionable matter. Altogether, 40 miles of new highways were constructed around the reservoir to replace the original roads within the reservoir. This work required the construction of ten new bridges, one of which has a span 200 feet long and another has a total length of 1,120 feet. The relocation of the Ulster and Delaware railroad required the construction of 11 miles of new road-bed and track.

The quality of the water in a large reservoir, as indicated by the temperature, turbidity and suspended microscopic growths, varies with the depth and with the seasons of the year. The gate-houses through which the water is drawn from the Ashokan reservoir into the aqueduct are so arranged that water may be drawn from either basin at the depth furnishing the most desirable water.

*The Catskill Aqueduct.*—The water impounded in the Ashokan reservoir is delivered at the gate-chamber into the Catskill aqueduct, a large conduit which extends across country through Ulster and Orange counties to Storm King in the Highlands where it crosses the Hudson river, thence down the east side of the Hudson river through Dutchess, Putnam and Westchester counties to the Kensico reservoir, an intermediate reservoir on the Bronx river above White Plains, and to the Hill View reservoir, a distributing reservoir just beyond the New York City line in Yonkers, a total distance of 92 miles, and thence as City Tunnel No. 1 and large pipe conduits through the City to the Silver Lake reservoir in Richmond borough, a further distance of 27 miles. The flow of water in the aqueduct is controlled by electrically-operated sluice-gates in the gate-chambers at the outlets of the Ashokan, Kensico and Hill View reservoirs.

The rugged and diversified character of the country traversed by the aqueduct required several different types of construction, the cut-and-cover aqueduct, the pressure tunnel, the grade tunnel and the steel-pipe siphons, which are shown on the plate on page 13.

Where the topography permitted and the elevation of the ground approximated that of the level of the flowing water in the aqueduct, the cut-and-cover type was used. This type was the least expensive and was built for a total of 55 miles.



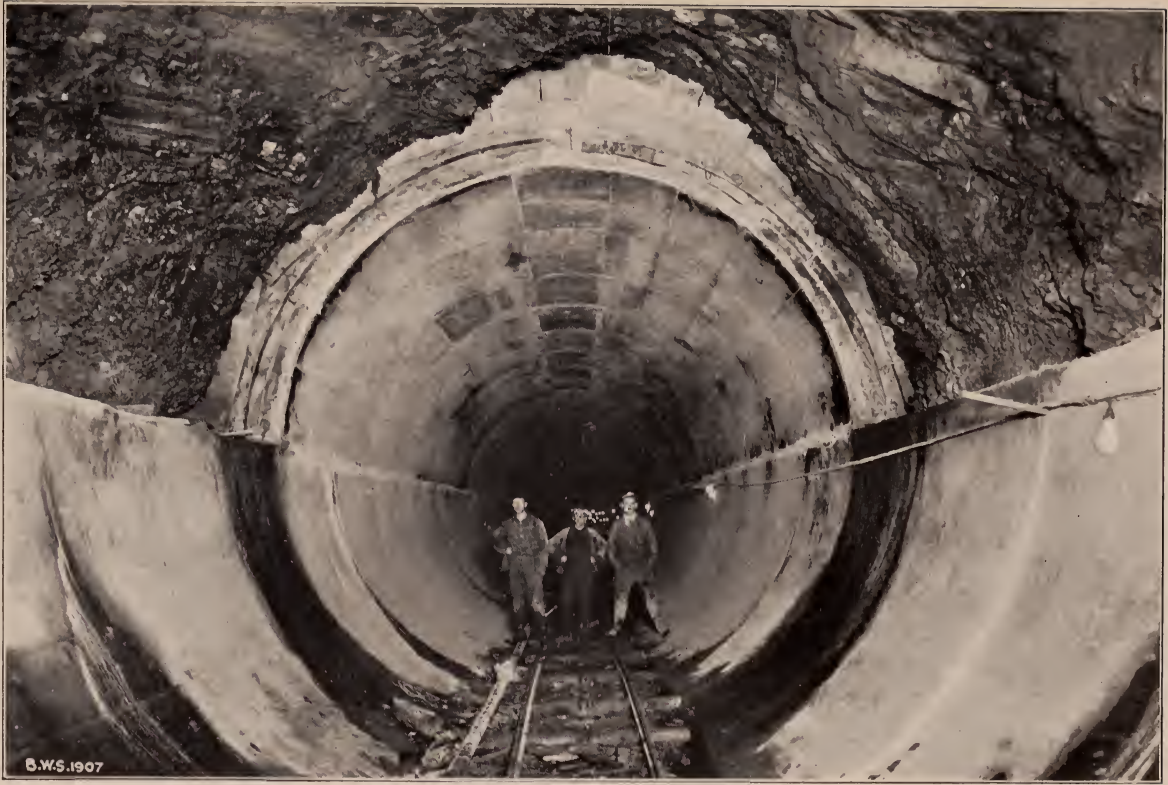
The construction of cut-and-cover aqueduct. In the foreground the concrete invert, or bottom, is being placed and immediately back of it are the steel inside forms, followed by a section where the steel outside forms also have been placed ready to receive the concrete, brought on the railroad and lifted into place by the locomotive crane. In the background is completed aqueduct ready to be covered with earth embankment.

The construction consisted of excavating a trench to subgrade or building an embankment on which a floor or invert of concrete was placed. Resting upon the sides of the invert and bonded to it, the side-walls and arch of concrete, without steel reinforcement, were poured between steel forms to the desired horseshoe shape. From outside to outside of the masonry required a trench 28 feet wide, or about as wide as between curb to curb of a New York cross-town street. That portion of the aqueduct north of the Kensico reservoir is 17 feet high and 17 feet 6 inches wide in inside dimensions and has generally a slope of about 1.1 feet per mile, which is sufficient to allow the desired flow of water to pass by, nearly, although not completely, filling the aqueduct. Between the Kensico and Hill View reservoirs the cross-section was enlarged to a hight of 17 feet 6 inches and a width of 18 feet. These cut-and-cover sections are sufficiently large to pass railroad trains.

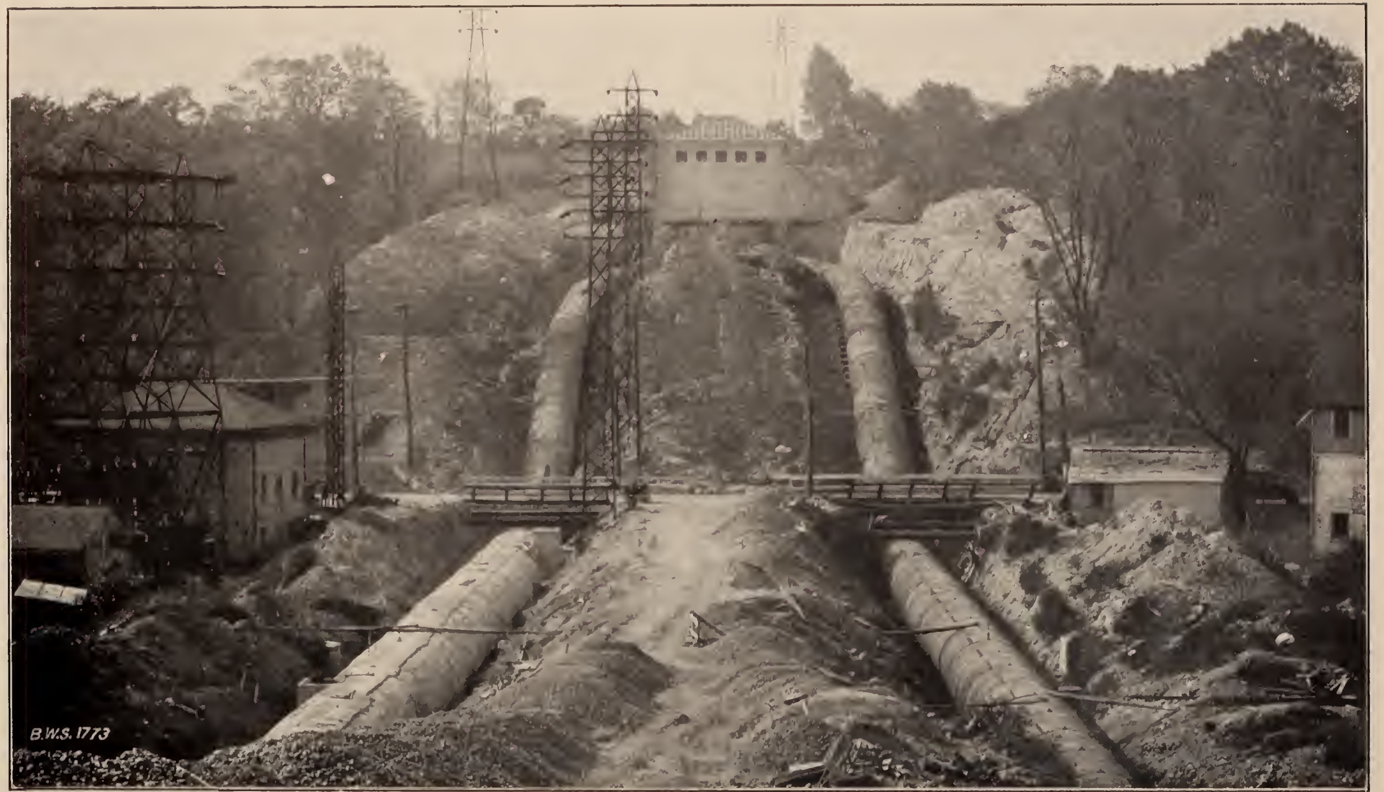
Where hills or mountains were encountered and it would have been impractical or uneconomical to avoid them, tunnels were driven through such obstacles and lined throughout with concrete without steel reinforcement. In this, the grade-tunnel type, the water flows as in the cut-and-cover type, that is, as in an open channel. This type also has a horse-shoe shape, but of lesser widths than the cut-and-cover sections, and is built on steeper longitudinal slopes. There are twenty-four of these grade tunnels between the Ashokan and Hill View reservoirs, aggregating 14 miles in length; those between the Ashokan and Kensico reservoirs are 17 feet high and 13 feet 4 inches wide inside, and south of the Kensico reservoir they are 17 feet 6 inches high by 13 feet 9 inches in width.

Where valleys were encountered, it was not possible to carry the aqueduct along at the natural elevation or gradient which the water would take, except as it be placed at a prohibitive expense on viaducts of great length and height like the Roman aqueducts. In such cases, types of construction were adopted that could be built at or below the ground surface in the valleys to withstand the water pressures in the aqueduct below the hydraulic gradient. In the larger valleys, the pressure-tunnel type was used, which consisted of a circular tunnel driven deep enough below the surface of sound rock in the valley bottom so that the rock and the weight of the overburden would withstand the water pressure in the tunnel. The tunnel is connected at either end to the aqueduct by vertical circular shafts, also in suitable rock. The tunnels and shafts were lined throughout with concrete without steel reinforcement and all seams around the concrete and in the rock were filled by forcing in under pressure thin grout made of Portland cement with or without sand. Drainage shafts were constructed so that each pressure tunnel can be unwatered for inspection, cleaning and repair. Besides the end and drainage shafts, other intermediate shafts were sunk to aid in excavating and lining the tunnels. These construction shafts were afterwards sealed with deep concrete plugs just above the tunnel and partially refilled, near the top, with rock debris and earth supported on concrete arches across the shafts. There are five of these pressure tunnels between the Ashokan and Hill View reservoirs, totaling 17 miles in length and varying in diameter from 14 feet to 16 feet 7 inches.

The most important of the valleys to be crossed was that of the Hudson river, where the tunnel was driven in granitic rock at a depth of 1,114 feet below sea level. This 14-foot tunnel extends from a shaft at Storm King mountain on the west bank to another shaft on the east side of the river at Breakneck mountain, a distance of 3,022 feet.



Rondout pressure tunnel, 14 feet 6 inches in diameter, during construction, showing the finished concrete lining, with the arch still to be placed in foreground.



Elmsford steel-pipe siphon, looking toward the south chamber, with the east and west lines, each 11 feet 3 inches in diameter, under construction on either side of the line previously laid. This is one of the fourteen localities along the Catskill aqueduct where the steel-pipe-siphon form of construction was employed. The steel pipes were encased in concrete, lined with mortar and covered with a grassed embankment of earth.

Across the smaller valleys or where the rock was not suitable for a pressure tunnel, riveted steel pipes encased in concrete and lined with two inches of cement mortar were laid in a trench just below the natural surface and covered with a protective grassed embankment of earth. This is known as the steel-pipe-siphon type, although it is not truly a siphon, but rather an inverted siphon. There are fourteen of these siphons, totaling 6 miles. In the construction of the aqueduct, it was deemed expedient to defer the complete installation at these fourteen points until such time as the Schoharie development was well under way. As the result of this decision, only one of the three lines of pipes necessary for developing the full capacity of the Catskill aqueduct was installed initially at each siphon, one line being sufficient to carry the yield of the Esopus creek. The pipes first placed are from 9 feet 6 inches to 11 feet 3 inches in internal diameter and are made of steel plates from $\frac{7}{16}$ inch to ¾ inch in thickness, riveted together.

From the Hill View reservoir, Catskill water is delivered through the Boroughs of The Bronx, Manhattan and Brooklyn in City Tunnel No. 1, a circular tunnel in solid rock, 18 miles in length, which is similar to the pressure tunnels of the aqueduct north of the City except in the construction of the shafts, and which is 15 feet in diameter at the Hill View reservoir and reduces in diameter from 15 feet to 14, 13, 12 and 11 feet.

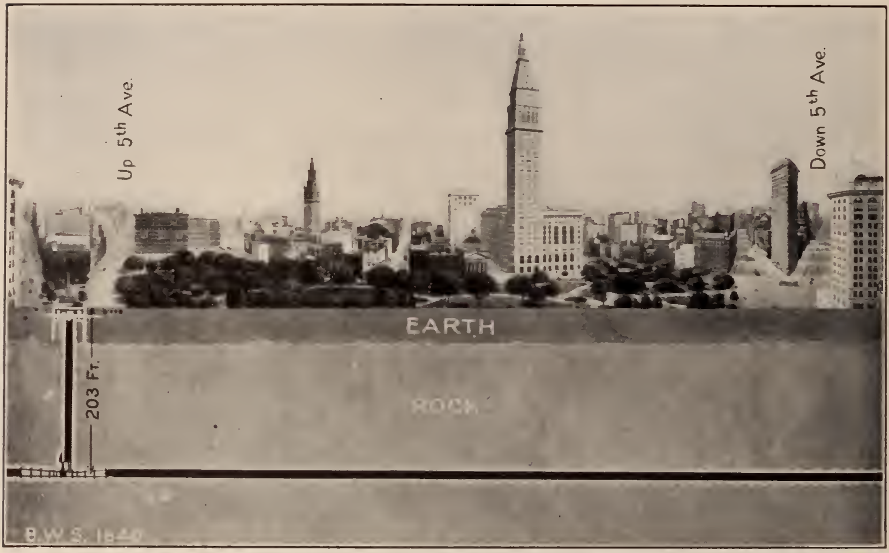
City Tunnel No. 1 was constructed from twenty-five shafts, including the downtake shaft at the Hill View reservoir. These shafts, about 4,000 feet apart, were located in parks and other places where their construction interfered very little with traffic. The tunnel is at depths of 200 to 750 feet below the street surface, thus avoiding interference with streets, buildings, subways, sewers and pipes. The waterway of the tunnel is lined throughout with concrete masonry. Through twenty-two of the shafts the water is delivered into the street mains. These connections from the tunnel to the mains are made by means of vertical riveted steel pipes (called risers) embedded in concrete in the upper part of each shaft and lined with concrete to prevent corrosion. Provision is made at two of these shafts for unwatering the tunnel, whenever necessary, for inspection, cleaning or repairs.

Unusual features in connection with the operation of the tunnel are the bronze riser valves in the shafts, 48 inches and 72 inches in diameter, and the section valves, 66 inches in diameter, also of bronze. The former are located about 100 feet below the top of sound rock and are designed to close automatically in case of an important break in the valve-chamber or in the street mains causing an abnormally large flow of water; they can also be closed by hand from within the chambers at the shaft tops. The section valves, two in number, are located across the main tunnel at the bottoms of Shafts 13 and 18, and permit the tunnel to be divided into parts and drained in sections without putting it entirely out of commission.

At Shaft 3 at the northerly end of the Jerome Park reservoir and at Shaft 10 in St. Nicholas park, connections were made to the Jerome Park reservoir and the Croton aqueducts, respectively. At the former shaft, the Department of Water Supply, Gas and Electricity has installed pumps of 60 million gallons per day capacity for pumping Croton water from the Jerome Park reservoir into City Tunnel No. 1, thereby using City Tunnel No. 1 to deliver Croton water at Catskill pressure to different parts of the City.

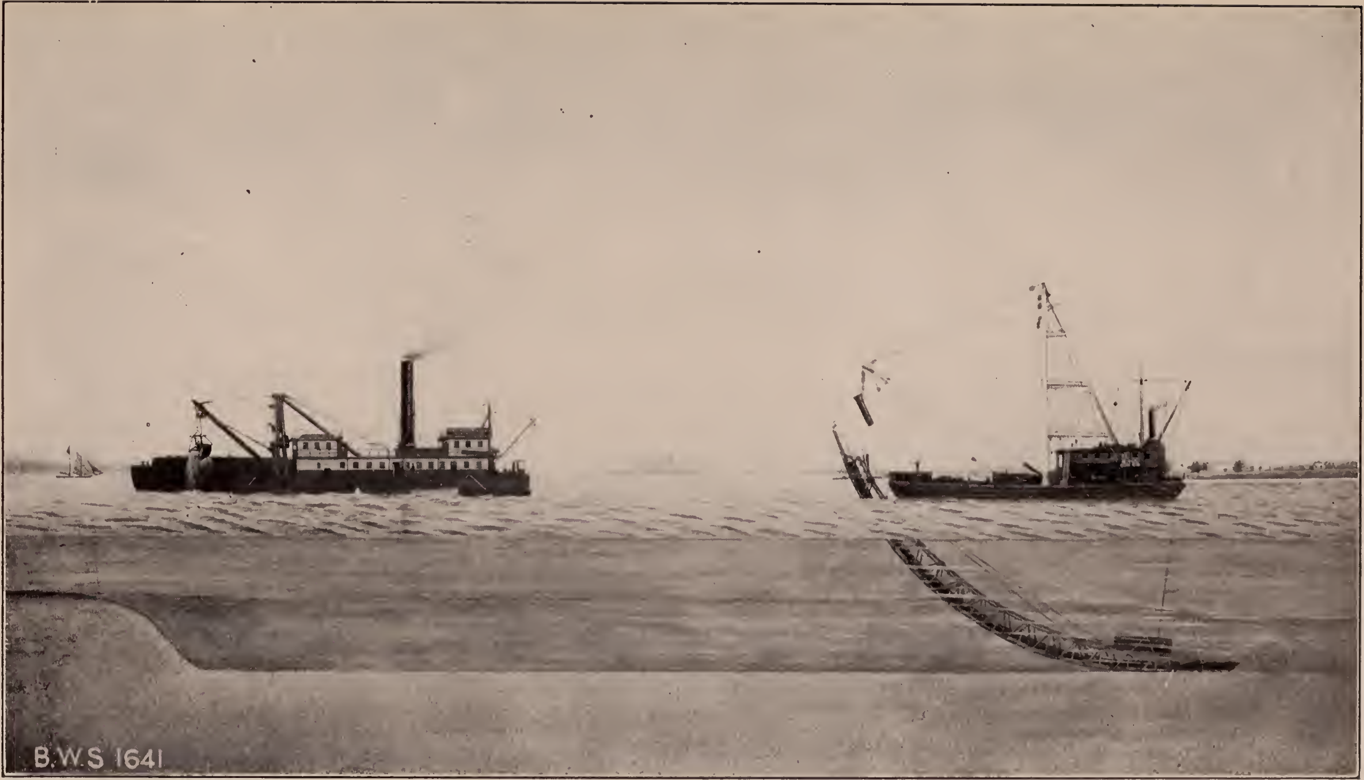
From Shafts 23 and 24, the two terminal shafts of City Tunnel No. 1 in Brooklyn, delivery conduits of steel and cast-iron pipe-lines, 39 miles in aggregate length and 48 inches to 72 inches in diameter, extend into Queens, Richmond and distant parts of Brooklyn. A 36-inch, flexible-jointed, cast-iron pipe-line buried in a trench in the harbor bottom and, later, a 42-inch pipe-line of the same type of construction, were laid across the Narrows to the Staten Island shore. The total length of the delivery system in use at the end of 1935, including City Tunnel No. 1 and the major pipe-lines, is about 57 miles. To this, City Tunnel No. 2 hereinafter described makes an addition of 20 miles.

*The Kensico Reservoir.*—The Kensico reservoir, in Westchester county, 30 miles north from the City Hall, was designed to contain sufficient Catskill water for maintaining the supply over a period of about two months. It serves as an emergency reservoir, so that the flow to the City will not be interrupted while the 75 miles of aqueduct between it and the Ashokan reservoir are at any time out of service. This reservoir is formed by the Kensico dam, across the valley of the Bronx river, about three miles north of White Plains near the site of a small dam which was built in 1884 as a part of the old Kensico reservoir, in which were stored the waters of the Bronx and Byram rivers. Its capacity is 29 billions of gallons, and its surface elevation is at 355 feet above mean tide at New York. The area of its water surface is 2,218 acres and the marginal protective strip around its entire circumference is in few places less than 500 feet wide.



Full circle panorama of New York City's streets around Madison Square as it was in 1917, when City Tunnel No. 1 was put into service, showing Shaft 18 and a portion of City Tunnel No. 1 in the rock more than 200 feet beneath the surface. Old Madison Square Garden tower, the Metropolitan tower and the Flatiron Building are easily recognized from left to right.

The Kensico dam is a gravity masonry structure built of cyclopean masonry, faced on its up-stream side with concrete blocks and with granite masonry on its



Laying Narrows Siphon No. 1 from Brooklyn to Staten Island. At the left is the clam-shell dredge boat with its scows and at the right the pipe-laying barge and the submerged bridge used to support the 36-inch flexible-jointed cast-iron pipe-line as it was put together. The barge and bridge were moved forward as the pipes were added to the line so that the pipe-line was paid out like a chain into the bottom of the trench. Subsequently the pipes were covered with sand and gravel. Narrows Siphon No. 2, which consists of 42-inch pipes, was constructed in a similar manner.

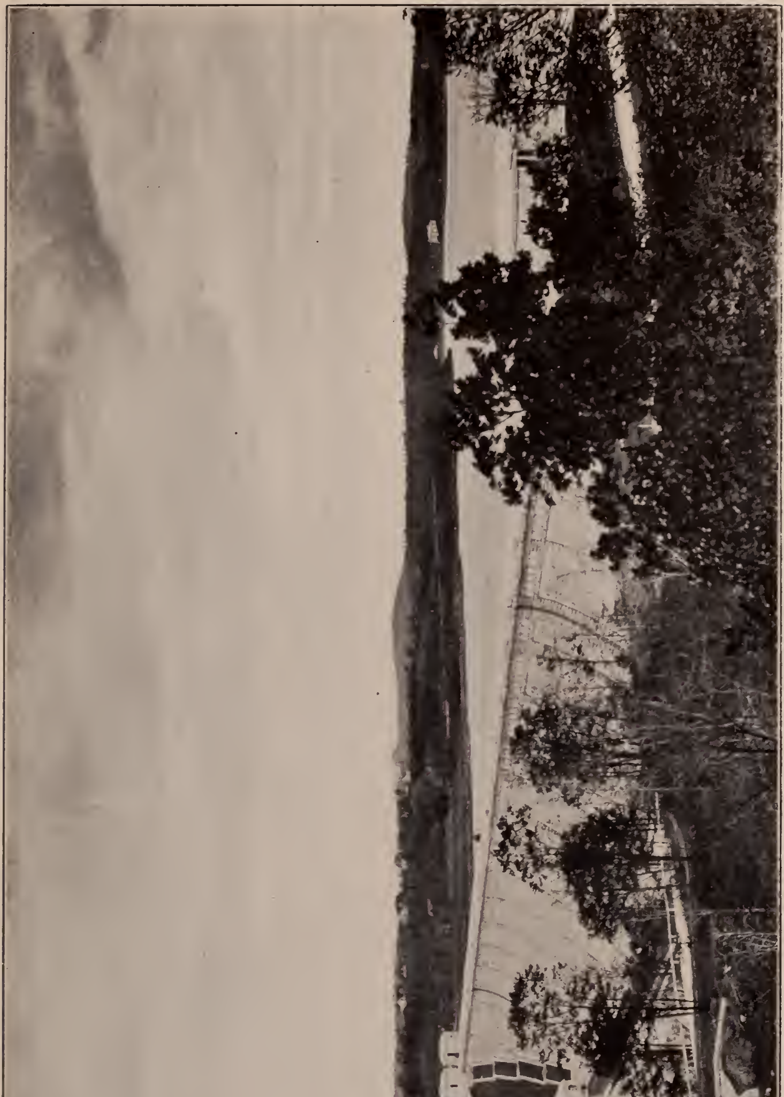
down-stream face. In order to provide for the movements which result from seasonal changes of temperature, the dam is divided into sections by contraction-joints spaced about 80 feet apart. The photograph on page 23 indicates the architectural treatment which was developed on the down-stream face of the dam. Local stone was used for the facing of the dam and an effort was made to secure as rough and rugged an appearance as was consistent with the principles of the adopted design. The Kensico dam is one of the great masonry structures of the world. It contains altogether nearly one million cubic yards of masonry,—about one-third that which the Egyptians placed in the Great Pyramid. However, of the large amount of masonry in this dam, only about one-third is visible above the surface of the ground. At the point of greatest hight it rises 307 feet above the rock foundation on which it rests.

A new highway system, rendered necessary by the construction of the Kensico reservoir, embraced the construction of 15 miles of road on which were a number of bridges, one of them a reinforced-concrete structure of five arches each of about 127-foot span. This bridge carries the highway over an arm of the reservoir, and the roadway at the center is 107 feet above the reservoir bottom.

Catskill water enters the Kensico reservoir near its upper end and is drawn from the lower end through a system of gates located in chambers about one mile north from the Kensico dam. At this point, provision is made for controlling the rate at which the water is drawn, for screening and for sterilizing it with liquid chlorine. Here also has been provided a large aeration basin in which the water is thrown into the air through 1,599 nozzles. This operation results in thoroughly mixing the water with air and thus aiding its purification.

*The Hill View Reservoir.*—The Hill View reservoir, which is located on the highest available ground in the City of Yonkers just north of the New York City line and 15 miles south of the Kensico reservoir, is an uncovered artificial reservoir of the earth embankment type, lined with concrete. It has a depth of 36½ feet, a water-surface area of 90 acres and holds 900 million gallons. Its function is to equalize the difference between the use of water in the City, as it varies from hour to hour throughout the day, and the steady flow in the aqueduct. Its original outlet is the vertical downtake shaft of the original delivery tunnel of the Catskill aqueduct, City Tunnel No. 1, which goes under The Bronx and Manhattan to Brooklyn, and the pressure of the water delivered to the City through that tunnel is due to the elevation of the water surface in the Hill View reservoir, 295 feet above sea level. The Catskill water is delivered to the City 160 feet higher than Croton water.

*The Silver Lake Reservoir.*—This small distribution reservoir for Staten Island at the end of the delivery conduits of the Catskill aqueduct, is about 2,400 feet long by 1,500 feet wide, uncovered, and formed by the natural ground and by artificial embankments. It is not lined with concrete. A dividing dike paved with concrete separates the reservoir into two basins, holding together 435 million gallons. From a gate-chamber built in this dike, reinforced-concrete conduits extend to the boundary of the reservoir, and steel and cast-iron pipe-lines connect these with Narrows Siphons Nos. 1 and 2, with the Staten Island service mains and with a pumping-station which raises Catskill water to the higher parts of the borough. The reservoir has a depth of 35 feet and the water surface is 228 feet above sea level.



The Kensico dam and portion of the reservoir, with the Kensico lower effluent chamber in right background.

## The Schoharie Creek Development

The Schoharie creek, a tributary of the Mohawk river, drains the northerly slope of the Catskill mountains in the Counties of Schoharie, Delaware and Greene. The mountain peaks along its southern boundary adjacent to the Esopus watershed have elevations of 3,500 to 4,000 feet above sea level, but the peaks on the westerly border fall off towards the north to 3,000 feet and those on the easterly border to 2,500 feet above sea level. All mountain slopes are forested.

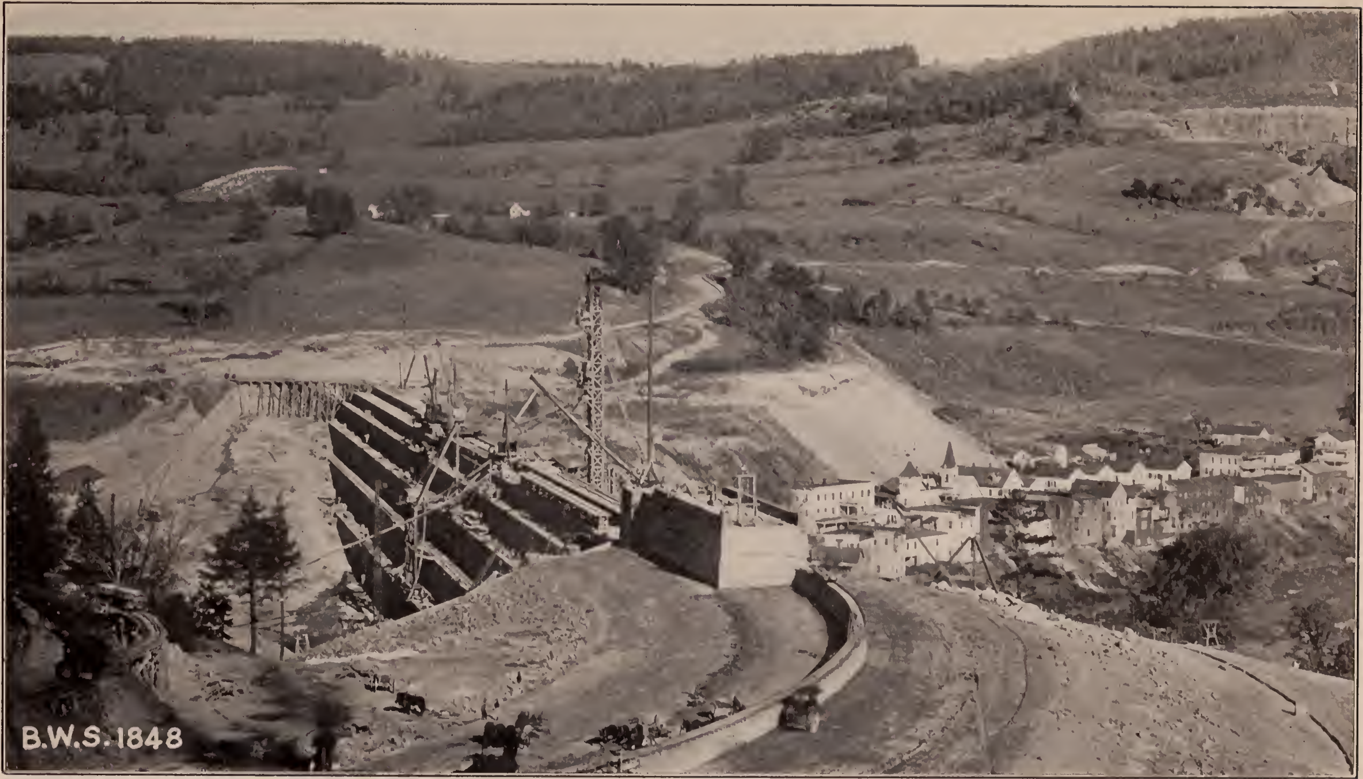
Such was the elevation on the Schoharie creek at the former Village of Gilboa, that it was possible to build the Gilboa dam there across the valley, to create the Schoharie reservoir in the valley above with a flow line at Elevation 1130 above sea level and to divert the run-off of 314 square miles of the Schoharie watershed through the Shandaken tunnel constructed under the Shandaken mountain range to the Esopus creek at Allaben, New York. From that point, the mingled waters of the Schoharie and Esopus creeks flow in the Esopus creek for a distance of 15 miles to the Ashokan reservoir and are carried in the Catskill aqueduct from that reservoir to the City.

*The Schoharie Reservoir.*—The Schoharie reservoir stores but 20 billion gallons, as a large part of the storage capacity necessary to equalize the Schoharie flow has been provided in the Ashokan reservoir. The Schoharie, like the Esopus creek, is subject to heavy floods and so, to conserve as much of the yield as possible, the Shandaken tunnel was built of such carrying capacity that the water can be delivered to the Esopus watershed at the rate of 600 million gallons or more a day, over twice the rated average supply that can be obtained from the Schoharie watershed.

The Schoharie reservoir is 5.8 miles long and 0.7 mile in maximum width, with a maximum depth of about 150 feet, the average depth being 57 feet. Its shore line is 16.5 miles long and the area of its water surface is 1,145 acres. It extends from Gilboa to Prattsville, the former being the only village disturbed. No railroad was affected by the construction operations. The flooding of the reservoir property required the construction of 12.4 miles of new highways to replace the 13.6 miles that were abandoned, and two steel bridges were built in connection with the new highway system. The City acquired a marginal strip around the shore line of the Schoharie reservoir for sanitary protection of the water, and practically everywhere the highways are the boundary line of the lands acquired by the City.

The Gilboa dam, located just below the former village of the same name and about three miles northeasterly from the Village of Grand Gorge, is composed of two parts,—an overfall masonry portion about 1,300 feet in length, with the crest at Elevation 1130 feet above sea level and having a maximum hight of 182 feet and a width of 158 feet at the base, and an earth section at Elevation 1150, with core-wall, approximately 700 feet long. A wide channel along the down-stream toe of the masonry portion serves to convey the overflow flood waters into the bed of the Schoharie creek below the dam.

The overfall portion of the dam is founded on solid rock and was constructed of cyclopean masonry consisting of large blocks of stone buried in concrete; the water side is faced with natural stone and the down-stream face is made in large steps from 7 to 20 feet in tread and rise, all faced with natural stone, with the overfall corners composed of the largest possible stones set on edge and thoroughly



General view of the Gilboa dam, dike and spillway channel during construction, looking easterly from the westerly end of the dike. To the right is the Village of Gilboa; also a portion of the Schoharie creek, the flow of which was carried through the stream-control conduit in the dam.

anchored. Masonry construction was carried up in sections about 75 feet in length between contraction-joints which extend completely through the dam from the up-stream to the down-stream face and from the foundation to the crest. A copper strip $\frac{1}{16}$ inch thick by 7 inches wide spans each contraction-joint as a water-stop.

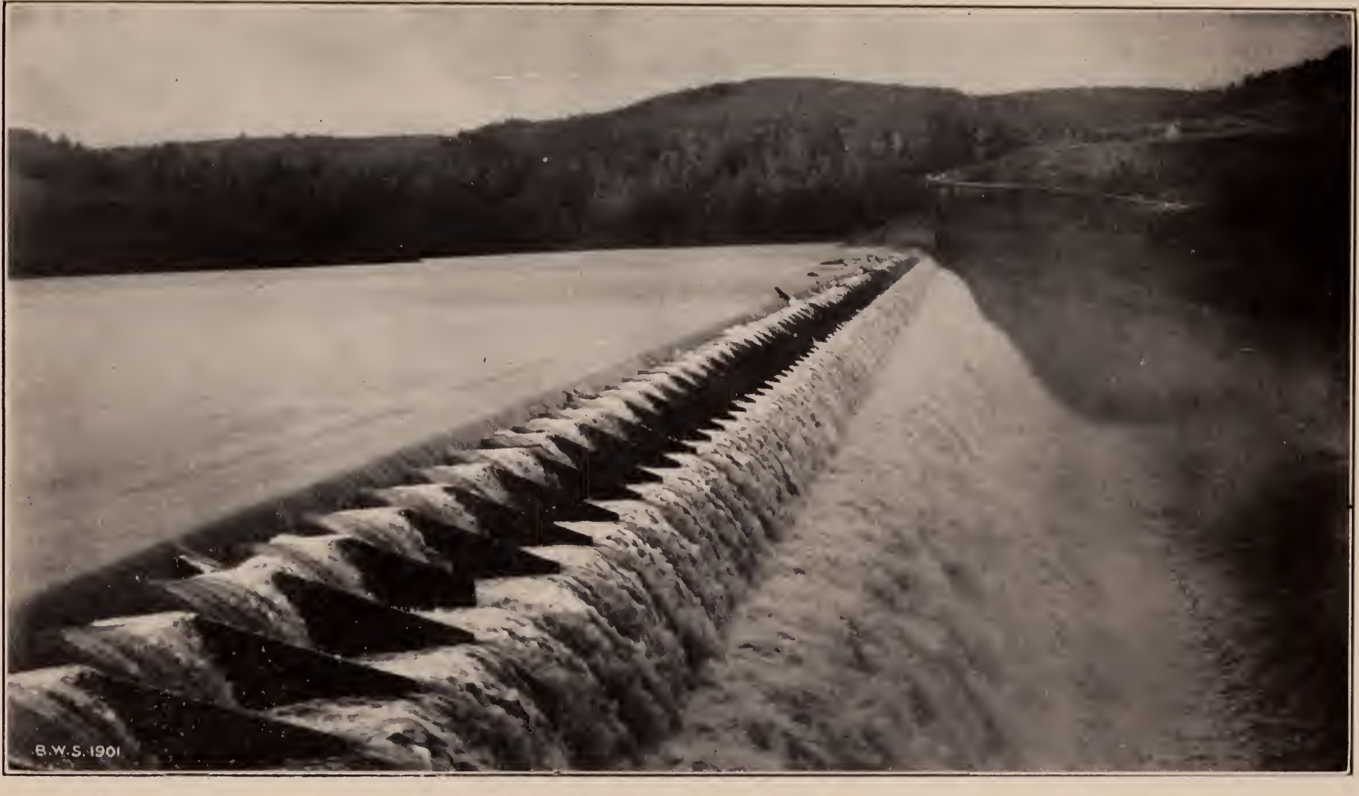
The 700-foot earth section for the left, or west, bank is curved in plan on about a 550-foot radius on the center line and was required because it was impracticable to carry the masonry section over the deep pre-glacial gorge, which here lies under the hill which flanks the dam on that side of the Schoharie creek. The masonry section is divided from the earth section by long, high and heavy retaining-walls which are faced with natural stone; these walls intercept the long earth slopes of the earth section, and beyond them the masonry section of the dam tapers into a core-wall which is continuous throughout the length of the earth section and extends deep into the hillside so as to intercept any underground water flow. The earth section in places is more than 100 feet in hight and is 32 feet wide at the top and upwards of 500 feet in thickness at its base. The embankment was compacted in 4-inch layers, the water side was paved with heavy stone and the down-stream face was covered with a thick layer of clean rock fragments.

*The Shandaken Tunnel.*—The supply of water impounded in the Schoharie reservoir is delivered to the Shandaken tunnel through hydraulically-operated sluice-gates in the gate-chamber at the intake which is located on the west side of the Schoharie reservoir about three miles above the Gilboa dam and about 3½ miles north of the Village of Prattsville. From the intake, the Shandaken tunnel extends in a generally southeasterly direction for a distance of 18.1 miles to a point in the Esopus valley just south of the Village of Allaben, where it discharges into the Esopus creek. The Shandaken tunnel was driven in rock, except for a short section in earth at the outlet, and was all lined with concrete masonry. Except for the northerly 3½ miles of pressure tunnel, in which it is depressed below the hydraulic gradient, it is a grade tunnel, horseshoe in section and concrete lined, with inside dimensions of 11 feet 6 inches in hight by 10 feet 3 inches in width, and has a uniform slope of 4.4 feet per mile. Seven intermediate construction shafts were sunk in constructing this tunnel, the aggregate depth of shafts being 3,238 linear feet and the maximum depth of a single shaft 630 feet. The minimum distance between these shafts is 1.3 miles and the maximum 2.7 miles. All shafts are circular and lined with concrete, and the seven intermediate shafts are protected at the top by a heavy galvanized grating. The upper portion of the intake shaft was so constructed that it acts as a Venturi meter, and the building over the gate-chamber at this shaft contains the keeper's residence.

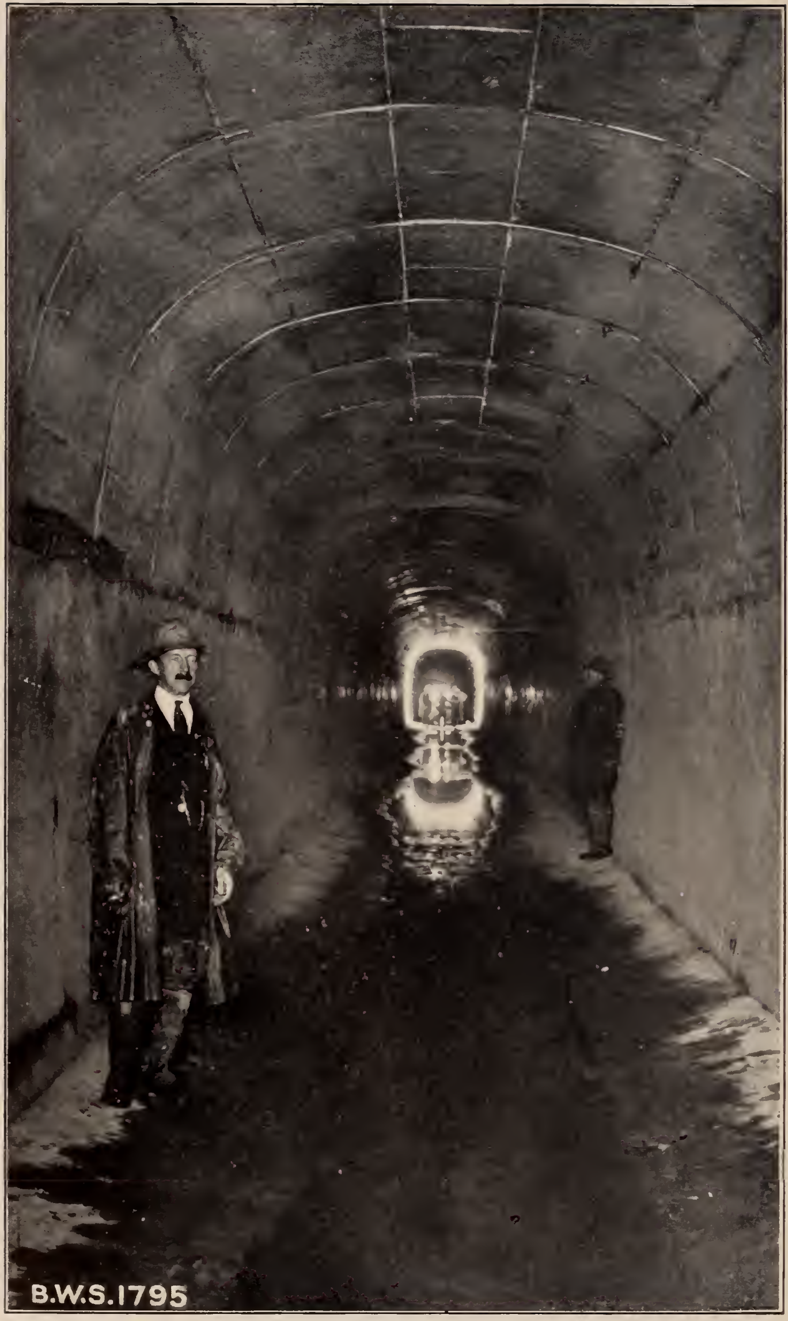
## Completion of the Catskill Aqueduct

Before the completion of the Schoharie Creek development, the last two of three steel pipe-lines in each of the fourteen steel-pipe siphons of the Catskill aqueduct were constructed to provide the necessary carrying capacity for both the Esopus Creek and Schoharie Creek developments. The construction of these additional steel pipe-lines followed the design of the original installations. They were built of $\frac{7}{16}$-inch to $\frac{9}{16}$-inch steel plates of diameters 7 feet 4 inches to 11 feet 3 inches.

The capacity of the finished Catskill aqueduct is somewhat in excess of 600 million gallons per day; in accordance with good design, the aqueduct will carry



General view of the Gilboa dam and the northerly portion of the Schoharie reservoir, with flood waters discharging over the crest of the masonry portion of the dam.



Section of the Shandaken tunnel.

approximately 20 per cent. more water than the conservative estimate of 500 million gallons per day now accepted as the dependable yield of the 571 square miles of watershed of the Catskill Water System. It will give a rough idea of the capacity of the aqueduct to point out that the water which the Catskill aqueduct can carry would be waist deep between the buildings in Fifth Avenue's shopping district if flowing at a comfortable walking speed.

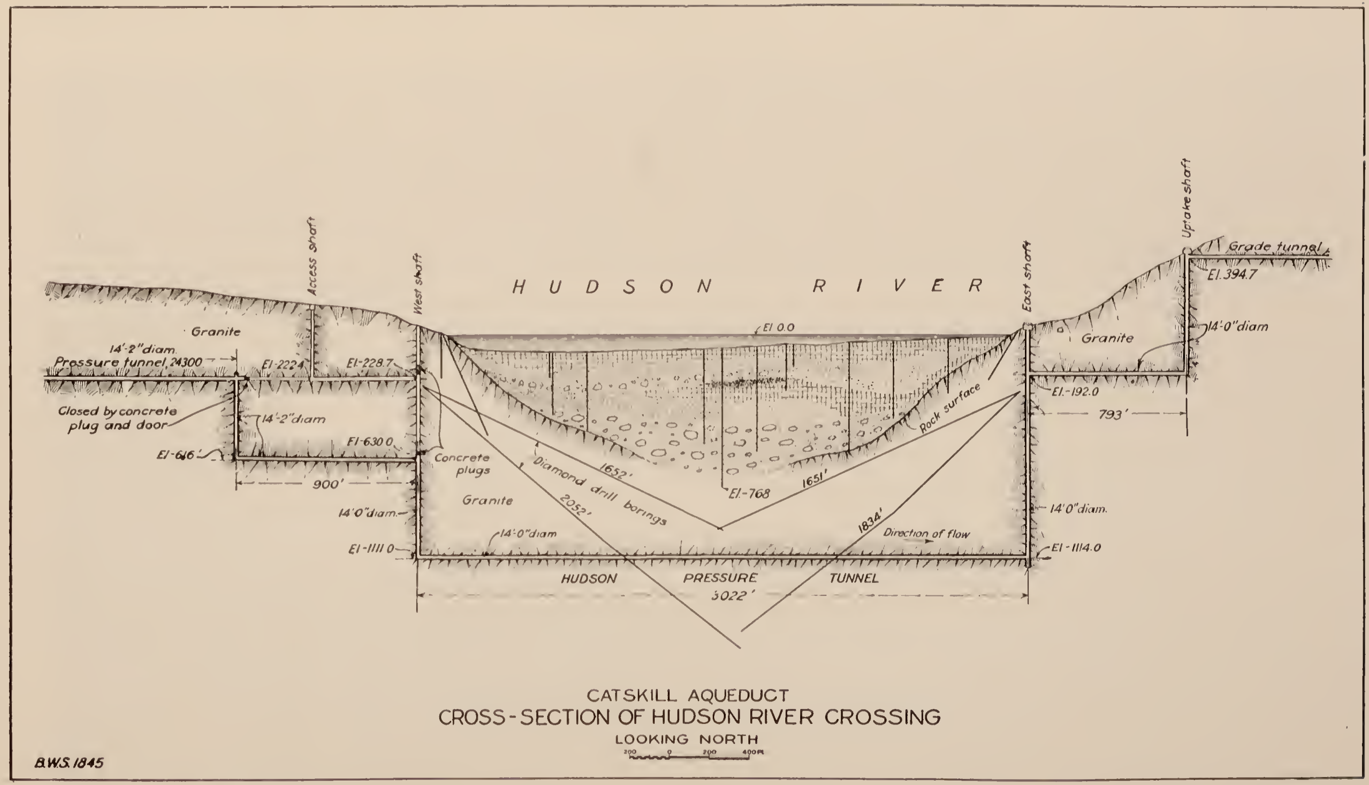
In 1931 the Department of Water Supply, Gas and Electricity installed pumps of 180 million gallons daily capacity at the Croton Lake gate-chamber and built a steel pipe-line to deliver this water into the Catskill aqueduct and thence to the Kensico and Hill View reservoirs.

## Surveys and Explorations

Before the construction of the Catskill aqueduct could be started, extensive surveys and subsurface explorations had to be made. The surveys alone included about 3,000 miles of line survey, besides the extensive topographical surveys of the reservoir sites and the final location of the aqueduct. For determining the most favorable locations and depths of the pressure tunnels, the geological explorations by means of borings into the rock, with diamond and shot drills, were necessary. Such explorations were also made for the locations of the dams and for other features of the work. In the aggregate, these borings amounted to 286,000 feet.

Before the Board began its work, the nature of the Hudson River bed from Albany to the sea and the depth to the bed-rock beneath it were matters of conjecture. The problem of bringing the Catskill water across the Hudson was of great importance and a number of possible crossings were explored. The best location proved to be that at the northerly end of the Highlands, where a band of granite crosses the valley, outcropping in Storm King mountain on the west side and Breakneck mountain on the east side. Endeavors were made by boring from scows on the surface of the river to determine the depth to the bed-rock, but this work proved tedious and expensive and, at best, could give information at only a few points. Winds, tides and traffic and the severe winter weather all militated against this method of exploration.

It was, therefore, determined to start a test shaft on each bank as close to the edge of the river as was practicable and, when suitable depth had been attained, to drill from a chamber in the side of the shaft inclined bore holes out under the river. From each shaft two diamond-drill core borings were made. In the first set, the holes were inclined rather steeply downward so as to reach the center of the valley at a depth about 1,500 feet below the surface of the river. The holes were each about 2,000 feet long. Many interesting difficulties were overcome and samples of the rock obtained for the whole distance. The second set of holes was then driven at a much flatter slope, taking the chance that they might possibly run out of the rock before reaching the center of the valley. These two holes, however, were wholly in rock and intersected at a depth of about 950 feet. Meanwhile, a drilling from a scow near the center of the river had reached a depth of 768 feet without entering the bed-rock, although having developed evidences of being near the rock, when the hole was lost through accident. With this information in hand, it was determined to locate the tunnel across the river at a depth of 1,114 feet below the river surface, being assured that at the shallowest place it would have somewhat more than the necessary minimum of 150 feet of sound rock above its roof.



CATSKILL AQUEDUCT
CROSS-SECTION OF HUDSON RIVER CROSSING
LOOKING NORTH

Cross-section of the Hudson River crossing of the Catskill aqueduct looking up-stream, showing the location of the tunnel and the diamond-drill borings made to explore the rock to determine its location.

## CONTRACTS

The Board is required by law to do practically all construction by contracts based on bids received after public advertisement. The work was divided into a number of parts, mainly along geographical lines, and contracts were entered into with companies who were familiar with the class of work involved, to perform the actual construction and furnish such necessary materials as were not found on the site of the work. There were 30 major contracts on the Catskill system, each amounting to between one and twelve million dollars, 51 amounting to between $100,000 and $1,000,000, while 83 minor contracts were let.

During the years of active construction, the contractors' daily forces ranged from a minimum of 500 to a maximum of 17,243, counting only the men actually and directly at work on the City's structures. If the large number of men in the cement mills, metal and other manufactories scattered throughout the country producing materials which were directly used in the construction work were included, the daily force would have reached a maximum of about 25,000.

## COST OF THE CATSKILL WATER SYSTEM

The expenditures that have been made by the Board of Water Supply on the works comprising the Catskill Water System, exclusive of City Tunnel No. 2, are tabulated below:

| | |
|---|---|
| Preliminary surveys and investigations | $1,673,803.86 |
| Ashokan reservoir and watershed | 31,563,857.67 |
| Catskill aqueduct | 68,017,101.33 |
| Kensico reservoir | 15,173,949.15 |
| Hill View reservoir | 5,659,635.24 |
| City Tunnel No. 1 | 23,232,315.77 |
| Delivery conduits | 12,781,311.72 |
| Silver Lake reservoir | 1,128,816.82 |
| Schoharie reservoir and watershed (including sewers and sewage disposal plants) | 14,464,723.62 |
| Shandaken tunnel | 14,387,757.27 |
| Total | $188,083,272.45 |

These costs include payments for lands and damages, the expenditures on construction and the costs of administration, engineering and police.

Up to the year 1934, in spite of the increased cost of almost every commodity, the water rates remained unchanged and the average cost to each individual in the City for all the water he used was about three-fourths of a cent per day. Subsequent to the increase in water rates in 1934, the cost for each individual's personal water supply needs has been little over a cent per day. It thus appears that water is among the cheapest of commodities for a resident in the City, and that its cost is less than that of any necessity of life, excepting only air.

## THE CATSKILL WATER SUPPLY

The Catskill Mountain area in which the drainage areas of the Catskill supply are located is, on the whole, an exceptional gathering ground, exposed as the higher mountains are to the moisture-laden east and southeast winds. The records of precipitation on the Esopus watershed show an average precipitation of 48 inches per year; that on the Schoharie watershed, less exposed to rain-bearing winds, an average of 41 inches per year.

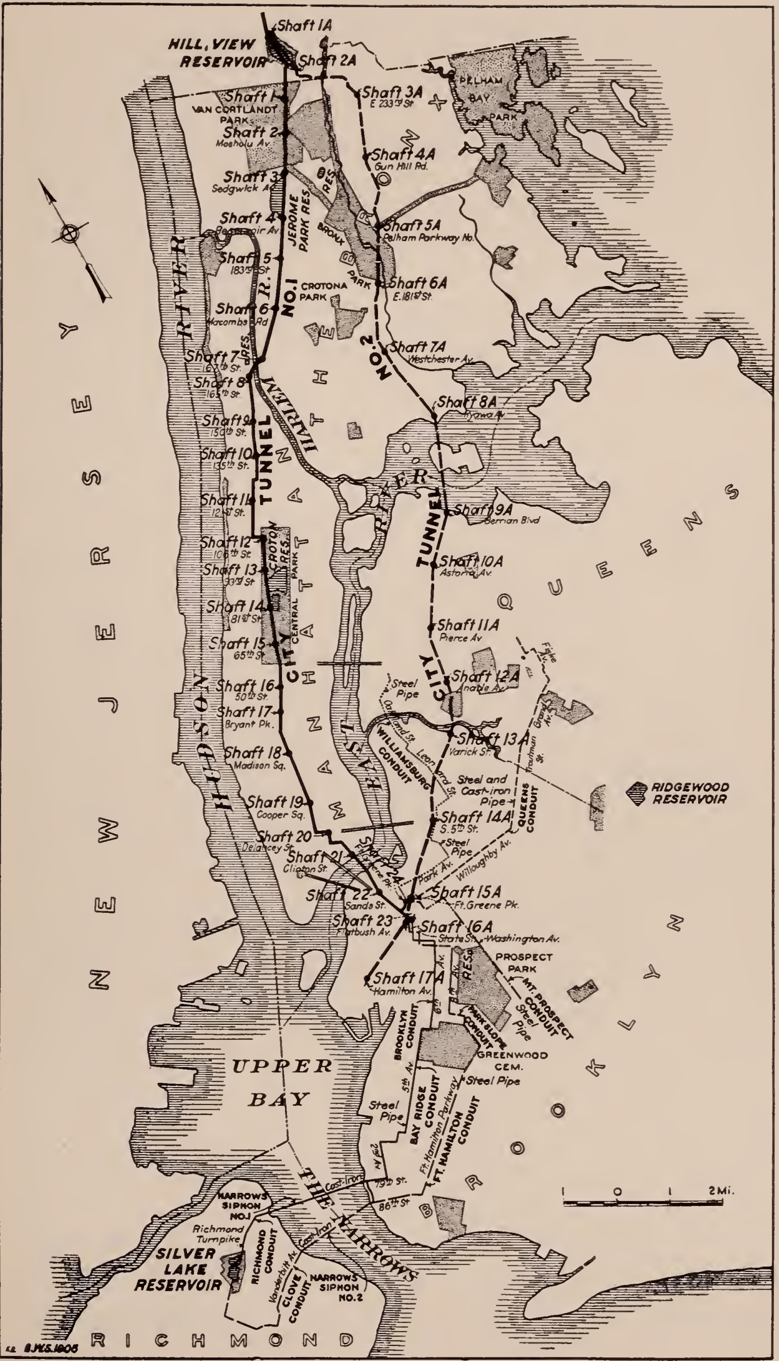
Both the Esopus and Schoharie watersheds are precipitous and the streams are flashy, there being, as a rule, large freshets in the spring and little flow during the summer. The percentage of the rainfall that appears as run-off is consequently large, being 30 inches depth, or 62.5 per cent., on the Esopus Creek watershed, and 26 inches depth, or 63.4 per cent., on the Schoharie Creek watershed. Compared with the yield of these watersheds, the run-off of the Croton watershed is about 22.5 inches depth and that of the Wachusett watershed of the Boston supply about 21.3 inches depth.

Measurements of the rainfall and run-off in the Catskill Mountain region, including the watersheds of the Esopus and Schoharie creeks, were begun by the Board of Water Supply immediately following its organization and have since been continued to determine the amount of water available. Stream measurements have recently been extended to the watershed of the Delaware river. The amounts of water drawn through the Shandaken tunnel and the Catskill aqueduct are measured at the outlets of the Schoharie, Ashokan, Kensico and Hill View reservoirs by Venturi meters constructed in these aqueducts with registers that indicate, register and record the amount of water passing.

The Catskill supply is collected from a thinly populated region of hills and mountains composed of shales and sandstones, with some conglomerates. The water is soft and of good sanitary quality, though occasionally turbid at times of flood when soil and other material are washed into the streams and clay beds are exposed. The total hardness of the Catskill supply is 20 parts per million, as compared with 43 parts per million for the Croton supply and 34 parts per million for the Ridgewood supply of Brooklyn.

*Temperature.*—The temperature of the water in the Ashokan reservoir during the winter months is quite constant at all depths. The surface water in the fall is cooled by the atmosphere and, as it becomes colder than the water beneath, a vertical circulation takes place whereby the colder and heavier water goes to the bottom, resulting in what is termed a turnover. During the middle of winter the general temperature is as low as 33 degrees Fahrenheit. During the summer months, however, there is practically no vertical circulation when the upper layers are being warmed by the sun. Then the water at the bottom of the reservoir reaches a temperature of about 60 degrees Fahrenheit, while the water near the surface generally is much warmer.

The water taken into the aqueduct after aeration at Ashokan has an average temperature of 50 degrees Fahrenheit, in the winter being as low as 33 degrees Fahrenheit and in the summer never reaching over 68 degrees Fahrenheit. The water, as it passes through the aqueduct at a brisk walking speed of three to four miles per hour, is everywhere in a closed duct and is not only protected from interference of ice, snow and pollution, but is thoroughly insulated by the surrounding concrete, rock and earth. Thus it is, that in the length of a day, which is the time it would take the water leaving the Ashokan reservoir to reach the City if not held in intermediate reservoirs, the temperature of the water would be but little changed.



City Tunnel No. 1 and City Tunnel No. 2, showing the locations of the tunnel lines and the various shafts; also the pipe conduits constructed by the Board of Water Supply in the Boroughs of Brooklyn, Queens and Richmond.

Actually, the water is stored in the Kensico and Hill View reservoirs and its temperature is raised a few degrees in summer and lowered a few degrees in winter.

*Removal of Turbidity.*—At a number of places in the Catskill watersheds there are banks of very fine clay-like earth on the hill slopes or along the streams and margins of the reservoirs. Under certain conditions of storm and flood, some of this earth is carried into the streams and by them into the reservoirs, making the water turbid. Most of this material causing the turbidity settles in the Schoharie and Ashokan reservoirs during the period of storage but, occasionally, some of the most finely divided particles find their way into the aqueduct. Provision has been made for eliminating, when necessary, the remaining turbidity by dosing with soda ash the supply in the aqueduct at the Ashokan reservoir and by adding alum, or sulphate of alumina, at a coagulating plant located at Pleasantville, about two miles above the Kensico reservoir. The alum forms a flaky precipitate, that is, flakes resembling unmelted snow flakes, which being heavier than the water, completely settle to the bottom during the storage period in the Kensico reservoir, carrying with them the finely divided particles held in suspension, thus completely clarifying the water.

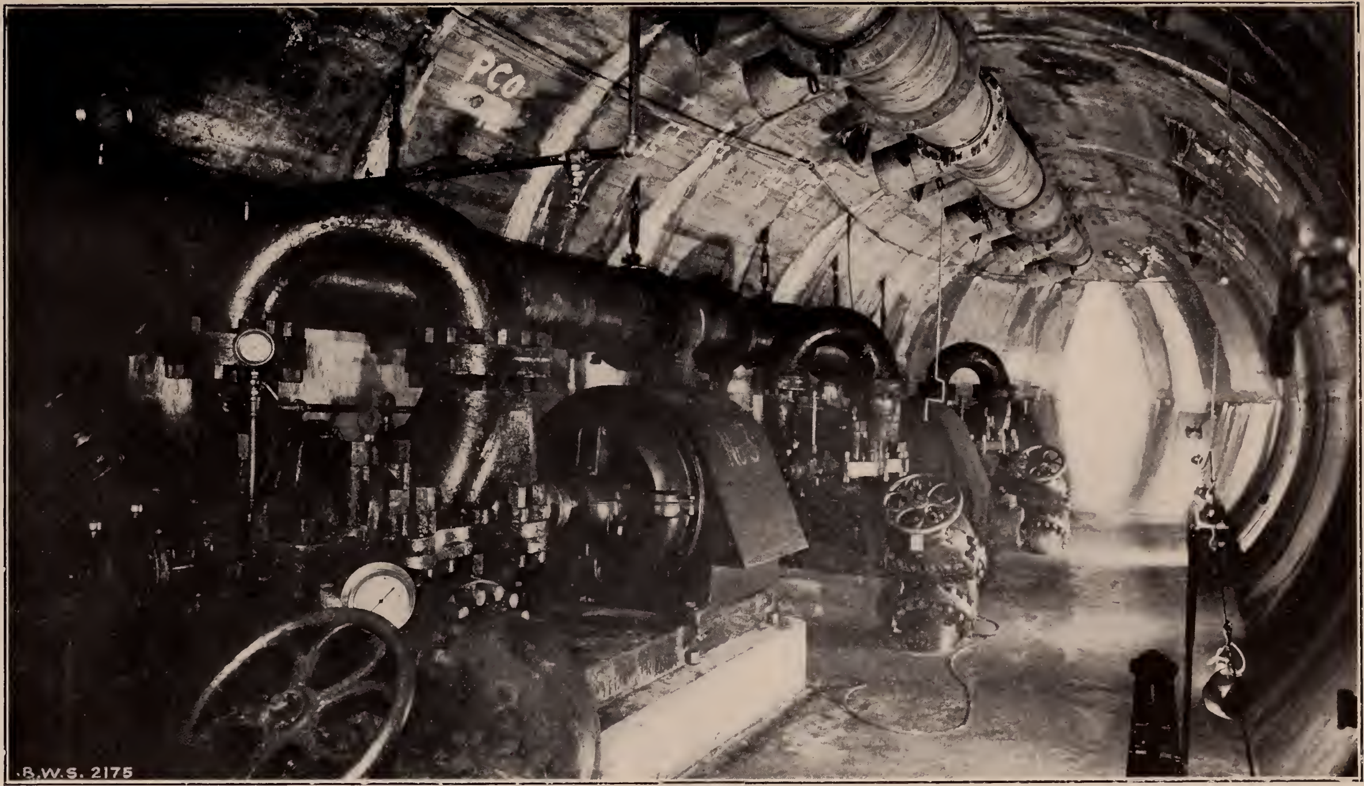
*Aeration and Storage.*—At two points, just below the Ashokan reservoir and again just below the Kensico reservoir, provision has been made for throwing the water into the air in fine spray, thus permitting thorough admixture of oxygen from the atmosphere and removal of objectionable gases and the breaking down of other matters causing tastes and odors. The two aerators are substantially alike and are great fountain basins, approximately 500 feet long by 250 feet wide, each containing 1,599 nozzles, through which sprays of water are thrown vertically into the air.

During the long storage of the Catskill water in the Schoharie, Ashokan and Kensico reservoirs, having an aggregate storage volume of 177 billion gallons, not only is suspended matter removed by sedimentation, but a general improvement occurs through bleaching by the sun, oxidation by the winds and sterilization by natural processes.

*Avoidance of Pollution.*—In order to safeguard the quality of the supply, marginal strips of land around the reservoirs, at Ashokan 1,000 feet wide and at the Kensico reservoir 500 feet wide, were obtained and have been cleared of undesirable growth and dead wood and reforested with evergreens. This tends to prevent erosion of the shores, prevents leaves of deciduous trees from blowing into the reservoirs and gives some control of the ground adjacent to the reservoirs to prevent gross contamination.

Much attention has been paid to the pollution of tributary streams, especially near communities where there is a considerable influx of summer visitors. The coöperation of communities has been obtained and the sanitary condition of hundreds of premises has been improved, resulting not only in local benefit but also in safeguarding New York City's supply.

Legislation was secured in 1923 enabling the City to negotiate with the authorities of villages and towns within the watersheds regarding the construction and maintenance of sewerage systems to further protect the supply from pollution. Such negotiations were entered into by the Board of Water Supply with the authori-



Pump-chamber at foot of Drainage Shaft 9A of City Tunnel No. 2, showing the three bronze high-pressure centrifugal pumps, electric motors and appurtenances for unwatering the tunnel when necessary for inspection or repair.

ties of the Villages of Tannersville and Grand Gorge on the Schoharie watershed, and sewerage systems for these two villages were subsequently built at a total cost of $700,000. A system was also installed on the Esopus creek at Pine Hill by the Department of Water Supply, Gas and Electricity.

*Chlorination.*—In order to eliminate the very small proportion of harmful bacteria which, in spite of all precautions, may reach the aqueduct, the water is sterilized by the introduction of chlorine. This chlorination is effected at three points: first, at the Ashokan screen chamber after the water has been discharged from the reservoir and has passed through the aerator; second, in the Kensico screen chamber after the water drawn from the reservoir has been aerated and, third, in the downtake chambers of the Hill View reservoir as the water flows into City Tunnels Nos. 1 and 2. The chlorine, in a liquid state, is delivered to the point of use where, as it is released from the containers, it reverts to the gaseous state and is led through control and measuring devices, placed in a water solution and delivered to the flowing water. Only sufficient chlorine is used to effect the desired sterilization.

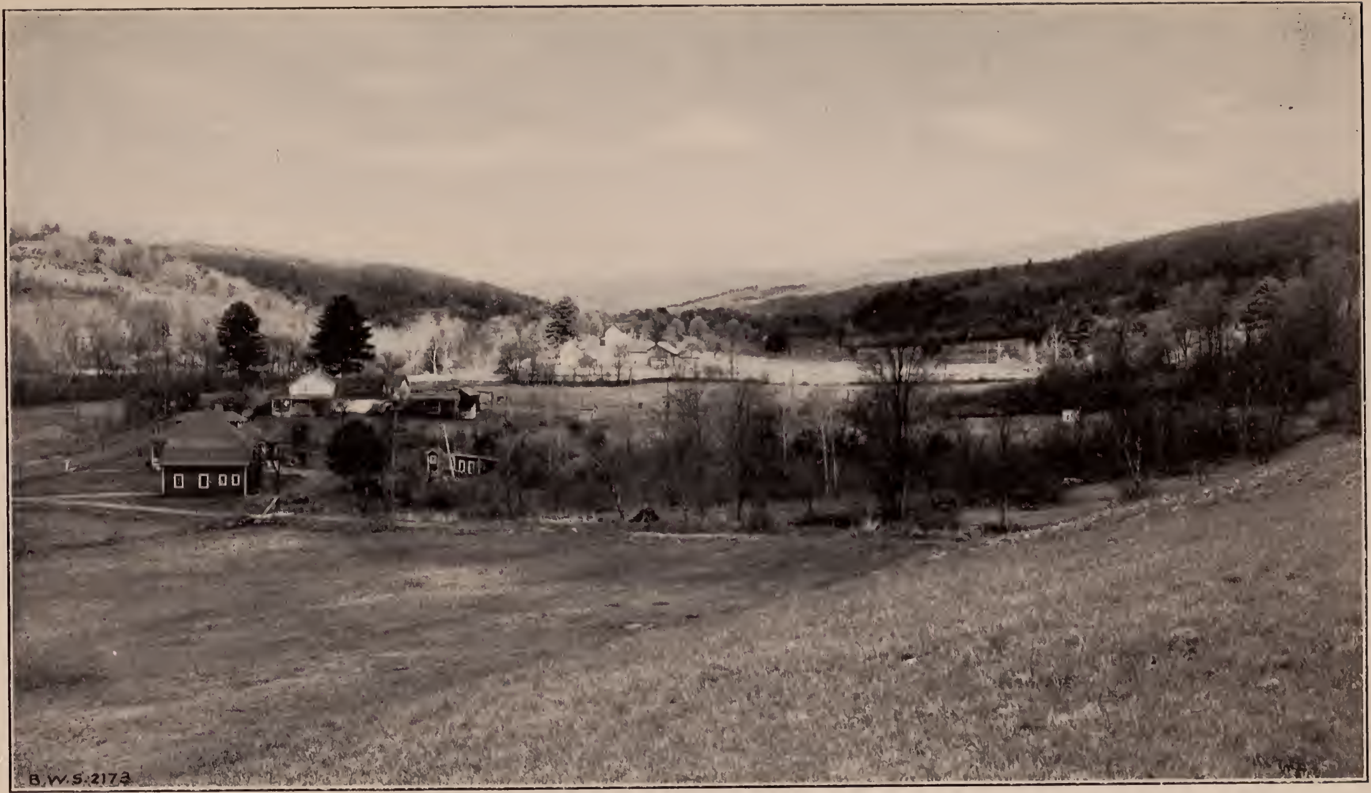
## CITY TUNNEL NO. 2

In anticipation of a large additional supply of water from new sources, and to provide for the better distribution of the Catskill supply to the outlying portions of the City which are remote from City Tunnel No. 1, the delivery tunnel built as a part of the Catskill aqueduct, the Board of Water Supply began in 1928 the construction of a second delivery tunnel known as City Tunnel No. 2, which is considerably larger than the first. The new tunnel extends from the Hill View reservoir through the Boroughs of The Bronx, Queens and Brooklyn, largely under streets, parks and other City lands, to a terminus in South Brooklyn, with connections in Brooklyn to City Tunnel No. 1 and to the large steel delivery conduits previously laid by the Board of Water Supply to the Boroughs of Brooklyn, Queens and Richmond. This tunnel is now completed.

City Tunnel No. 2 is 20 miles in length and 17 feet in finished diameter, except for the Hill View by-pass tunnel, 0.7 mile in length, under the Hill View reservoir, which is 21 feet in diameter, and the last 1.3 miles of the tunnel in Brooklyn borough, which is 15 feet in diameter.

This new tunnel was constructed through eighteen shafts, counting one of the double waterway shafts at the north end of the Hill View reservoir and both of the double waterway shafts at the south end, and these shafts were sunk to tunnel grade at depths of 361 to 766 feet below the surface and 100 to 553 feet below sea level.

At the Hill View reservoir, gate-chambers equipped with hydraulically-operated sluice-gates control the flow of Catskill water to City Tunnel No. 2. In Downtake Chamber No. 2, at the south end of the Hill View reservoir, chlorinating equipment has been provided for the treatment of the supply as it enters City Tunnel No. 2. At each of the fifteen riser shafts in the City, two risers with control valves well below the top of sound rock were constructed to carry the water from the tunnel to the underground valve-chamber at the surface in which valves have been installed to control the delivery of water to large delivery conduits and other street mains. From two of the shafts of City Tunnel No. 2 in Brooklyn, large steel conduits have been laid to the two terminal shafts of City Tunnel No. 1 to provide for the exchange of water between the two tunnels both to improve the pressure and to supply from one



General view looking up-stream of the Rondout Creek valley at the proposed site for the Lackawack dam of the Rondout reservoir. From here, the water will be conveyed through the Delaware aqueduct, a distance of 85 miles to the Hill View reservoir, where it will be available for delivery in New York City.

of these tunnels the southerly section of the other tunnel in the event of the northerly section or sections of that tunnel being shut down. Drainage of City Tunnel No. 2 is provided for at the shaft in Queens near the East river, and section valves across the tunnel at that shaft permit the northerly half of the tunnel to be cut off from the southerly half. The estimated cost of this tunnel is $58,000,000.

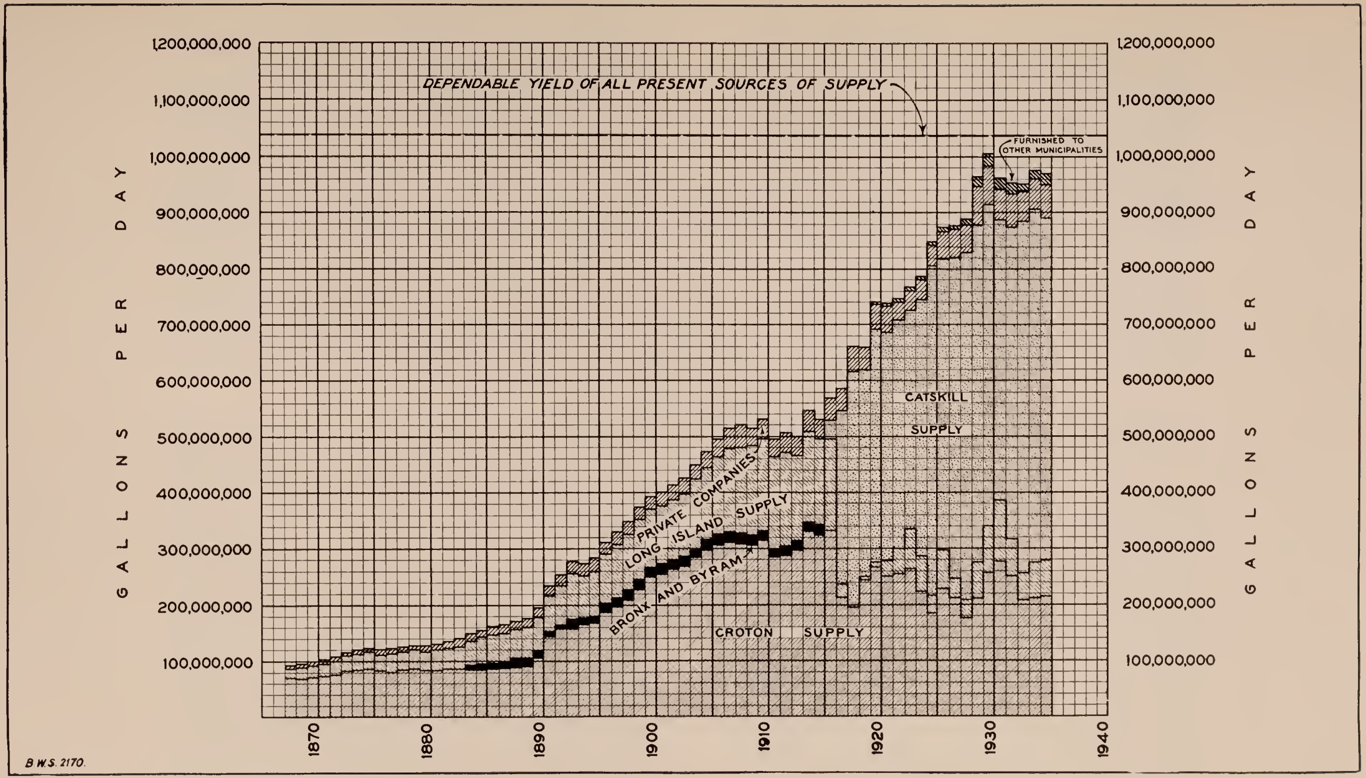
## THE DELAWARE PROJECT

When originally planned, the Catskill Water System was expected to meet the City's yearly increases in the water consumption for a period of about 25 years. Following the introduction of the Catskill water in 1917, the consumption increased each year at the rate of about 30 million gallons a day until the end of the year 1930, when 1,007 million gallons of water, but 32 million gallons per day less than the total amount of the dependable supply estimated at 1,039 million gallons per day, were consumed daily. Since 1930, as a result of the business depression, the use of water in the City has fallen off as much as 5 per cent., the result of decreased activity in business, manufacturing and commerce, as evidenced by empty stores, lofts and apartments. With the return of normal business activity, there will be a rapid increase in consumption and the demand for water will soon exceed the dependable supply.

The consumption in the City during the year 1935 averaged 950 million gallons daily, and an additional 20 million gallons daily were furnished to communities outside the City as required by law, making the consumption from the City's existing water supply systems 970 million gallons daily, or but 69 million gallons per day less than the dependable supply from all existing sources.

As early as June 17, 1921, the Board of Estimate and Apportionment authorized the Board of Water Supply to proceed with studies and investigations for an additional supply of water for the City of New York. It was concluded from the studies and investigations of all available sources in New York State that the most available and economical supply to serve the City's needs could be obtained from the tributaries of the Delaware river within the State. Since the Delaware river is an interstate stream, negotiations were entered into with the State of New Jersey and the Commonwealth of Pennsylvania relative to the use of its waters and, in 1925 and 1927, compacts were agreed upon by representatives of the three states but, in each case, were ratified only by the State of New York.

Following the failure of the interstate negotiations, a report, map and plan outlining the Board's recommendations as to the most available and best sources of new water supply for New York City were prepared and submitted to the Board of Estimate and Apportionment on July 27, 1927. This plan recommended the development of the Rondout creek, a tributary of the Hudson river, and the taking of a part of the flood waters of the following tributaries of the Delaware river lying wholly in the State of New York: the East Branch of the Delaware river, the Little Delaware river, the Beaver kill, the Willowemoc creek and the Neversink river. To reduce the cost of pumping Croton water, this plan also provided for the construction of the Delaware aqueduct through the Croton watershed and for the delivery into the Kensico reservoir and thence into the Hill View reservoir, 160 feet higher than the Croton aqueducts deliver it, of 100 million gallons daily of water now developed by the existing reservoirs on the higher levels of the Croton watershed. The plan provides for the development of the new sources in three stages, as follows:



Daily consumption of water in New York City and quantities supplied from the City's systems to outside municipalities, 1868 to 1935, inclusive; also the relation of consumption to the dependable yield of all of the City's present sources of supply.

> *First stage.*—The construction of the reservoirs on the Neversink river and the Rondout creek, together with the tunnel connecting the Neversink and Rondout and the aqueduct tunnel to the present West Branch reservoir on the Croton watershed, thus making available 170 million gallons daily of new and additional water. At the same time, the main aqueduct would be constructed from the West Branch reservoir to the Kensico reservoir and thence to the Hill View reservoir.
>
> *Second Stage.*—As the constructions above outlined approached completion, work on the second stage would be begun with the building of the reservoir on the East Branch of the Delaware river and the driving of the tunnel through to the Rondout valley, so as to make available 370 million gallons daily more of new and additional water and bring the total for the new system up to 540 million gallons daily.
>
> *Third Stage.*—As more distant future developments might require, the reservoirs on the Little Delaware river, the Beaver Kill and the Willowemoc creek would be constructed, together with the necessary connecting tunnels. These sources would make available a further supply of 160 million gallons daily and provide a total supply of 700 million gallons per day.

The cost of the proposed development to the end of the second stage was estimated at $272,587,000, such estimated expenditure to be spread over a period of about twelve years.

This plan was approved by the Board of Estimate and Apportionment on January 12, 1928, and by the State Water Power and Control Commission on May 25, 1929. Legislation necessary to render the provisions of Chapter 724 of the Laws of 1905 applicable to the development of these new sources was secured at the 1928 session of the Legislature.

Further progress on this project was seriously delayed by an action brought by the State of New Jersey in the United States Supreme Court on May 13, 1929, to enjoin the City and State of New York from diverting the waters of any of the tributaries of the Delaware river. Subsequently, the Commonwealth of Pennsylvania prayed the Court that it be permitted to intervene, and this request was granted.

On January 27, 1930, the United States Supreme Court appointed Charles N. Burch, of Memphis, Tennessee, as Special Master in the Delaware River Case to make findings of fact and conclusions of law, together with recommendations for a decree. After many hearings, the Special Master's report of February 2, 1931, was ordered filed on February 25, 1931. In that report, the Special Master recommended that the diversion of the Delaware by New York City be limited to 440 million gallons per day, this being the quantity contemplated in the first two stages of the project, and that the City be free to petition at a future date for the approval of an additional diversion. It was also provided in the Master's report that provisions for the treatment of sewage of the City of Port Jervis, New York, be made before any diversion is effected and that compensation water be delivered to the Delaware river during periods of low water. On May 4, 1931, the United States Supreme Court approved the Master's report and the decree was entered May 25, 1931. This decision makes available to the City, with the supply of 100 million gallons per day from the Rondout creek not affected by the litigation, a total supply of 540 million gallons per day. (See plate on page 5.)

It is now proposed to sink and line with concrete masonry all the shafts of the Delaware aqueduct from the Rondout reservoir to the City, and to do some preliminary work on the dam sites of the Delaware project, for which the sum of $20,000,000 was provided by the Board of Estimate and Apportionment in the Capital Outlay Budget on March 30, 1936.

With nearly 25,000 persons in camps during construction, the Aqueduct Police protected communities near the water-works. Their presence alone was a deterrent to those criminally inclined. They maintained order, protected person and property and enforced sanitary and other rules, as well as local ordinances and laws governing intoxicants, concealed weapons, speeding, etc.

# STATISTICAL ITEMS OF INTEREST IN CONNECTION WITH THE CATSKILL WATER-SUPPLY SYSTEM

## Land Acquired

| Structure | Acres | Square Miles |
|---|---|---|
| Schoharie reservoir | 2,372 | 3.7 |
| Shandaken tunnel | 80 | .1 |
| Ashokan reservoir | 15,222 | 23.8 |
| Kensico reservoir | 4,500 | 7.0 |
| Catskill aqueduct, Ashokan reservoir to City line | 2,279 | 3.6 |
| Filter site | 315 | .5 |
| Hill View reservoir | 164 | .2 |
| Silver Lake reservoir and City Tunnel No. 1 | 166 | .3 |
| Total | 25,098 | 39.2 |

## Statistics of Ashokan, Kensico and Schoharie Reservoirs

| | Ashokan | Kensico | Schoharie |
|---|---|---|---|
| Capacity, total | 130,000,000,000 gallons | 38,000,000,000 gallons | 22,000,000,000 gallons |
| Capacity, available | 128,000,000,000 gallons | 29,000,000,000 gallons | 20,000,000,000 gallons |
| Water surface | 8,180 acres=12.8 sq. miles | 2,218 acres=3.5 sq. miles | 1,145 acres=1.8 sq. miles |
| Land acquired | 15,222 acres=23.8 sq. miles | 4,500 acres=7.0 sq. miles | 2,372 acres=3.7 sq. miles |
| Elevation of top of dam, above tide | 610 feet | 370 feet | 1,130 feet |
| Length of reservoir | 12 miles | 4 miles | 5.8 miles |
| Length of shore line | 40 miles | 30 miles | 16.5 miles |
| Length of dams and dikes | 5½ miles | 3,300 feet | 2,000 feet |
| Main dam: | | | |
| total length | 4,650 feet | 1,825 feet | 2,000 feet |
| length of masonry portion | 1,000 feet | 1,825 feet | 1,300 feet<br>(Earth, 700 feet) |
| hight (maximum) | 252 feet | 307 feet | 182 feet |
| thickness at base (maximum) | 190 feet | 233 feet | 158 feet |
| thickness at top (minimum) | 23 feet | 28 feet | 15 feet |
| Width of reservoir: | | | |
| maximum | 3 miles | 3 miles | 0.7 mile |
| average | 1 mile | 1 mile | 0.4 mile |
| Depth of reservoir: | | | |
| maximum | 190 feet | 155 feet | 150 feet |
| average | 50 feet | 52 feet | 57 feet |
| Villages submerged | 7 | 1 | 1 |
| Permanent population of submerged area at beginning of work | 2,000 | 500 | 350 |
| Cemeteries removed | 32 | none | 7 |
| Bodies reinterred | 2,800 | none | 1,300 |
| Railroad relocated | 11 miles | none | none |
| Highways discontinued | 64 miles | 14.8 miles | 13.6 miles |
| Highways built | 40 miles | 15.1 miles | 12.4 miles |
| Highway bridges built | 10 | 4 | 2 |
| Earth and rock excavation | 2,500,000 cubic yards | 1,400,000 cubic yards | 555,000 cubic yards |
| Embankment | 7,300,000 cubic yards | 2,010,000 cubic yards | 880,000 cubic yards |
| Masonry | 900,000 cubic yards | 965,000 cubic yards | 483,000 cubic yards |
| Cement | 1,200,000 barrels | 897,000 barrels | 513,000 barrels |
| Maximum number of men employed | 3,000 | 1,500 | 800 |

## ELEVATIONS ABOVE TIDE IN NEW YORK HARBOR OF CATSKILL WATER AT VARIOUS POINTS

| | |
|---|---|
| Schoharie reservoir (flow line) | 1,130 feet |
| Shandaken tunnel, intake (invert) | 1,050 feet |
| Shandaken tunnel, portal (invert) | 970 feet |
| Ashokan reservoir, west basin (flow line) | 590 feet |
| Ashokan reservoir, east basin (flow line) | 587 feet |
| Catskill aqueduct at headworks (flow line) | 511 feet |
| Kensico reservoir (flow line) | 355 feet |
| Water level, Eastview filters | 322 feet |
| Catskill aqueduct at filter effluent (flow line) | 312 feet |
| Hill View reservoir (flow line) | 295 feet |
| Silver Lake reservoir (flow line) | 228 feet |

Water can now be delivered by City Tunnel No. 1 in lower Manhattan at an elevation from about 250 to 260 feet above tide level and in Brooklyn about 240 to 250 feet above tide level.

## DISTANCES FROM THE GILBOA DAM OF THE SCHOHARIE RESERVOIR

| | |
|---|---|
| To the Ashokan reservoir | 34 miles |
| To the Hudson River crossing | 85 miles |
| To Croton lake | 104 miles |
| To the Kensico reservoir | 115 miles |
| To the Hill View reservoir (New York City line) | 132 miles |
| To the Silver Lake reservoir | 159 miles |

## PRINCIPAL TOTAL CONSTRUCTION QUANTITIES—CATSKILL SYSTEM

| | |
|---|---|
| Earth excavation in open cut | 18,000,000 cubic yards |
| Earth excavation in tunnel | 58,500 cubic yards |
| Rock excavation in open cut | 1,300,000 cubic yards |
| Rock excavation in tunnel | 3,300,000 cubic yards |
| Masonry in open cut | 4,900,000 cubic yards |
| Masonry in tunnel | 1,300,000 cubic yards |
| Cement | 7,850,000 barrels |
| Cast iron | 34,000 tons |
| Steel | 76,000 tons |
| Bronze and brass | 3,300,000 pounds |

## WEIGHTS OF SOME LARGE SPECIAL VALVES AND FITTINGS

| | |
|---|---|
| Cast-steel dome on top of the Hudson drainage shaft | 46.25 tons |
| Bronze 66-inch section valve, City Tunnel No. 1 | 20.5 tons |
| Bronze 72-inch riser valve, City Tunnel No. 1 | 21.4 tons |
| Bronze 48-inch river valve, City Tunnel No. 1 | 9.4 tons |
| Bronze 72-inch by 48-inch by 48-inch shaft cap, City Tunnel No. 1 | 11.8 tons |
| Bronze 48-inch by 30-inch by 30-inch shaft cap, City Tunnel No. 1 | 4.8 tons |

## Brief Chronology of the Catskill Mountain and Rondout-Delaware Water Supplies

| | |
|---|---|
| Report of special committee to Manufacturers' Association; sources west of the Hudson river considered for Brooklyn | Mar. 15, 1897 |
| John R. Freeman's report submitted to Comptroller Bird S. Coler | Mar. 23, 1900 |
| Burr-Hering-Freeman Commission's report rendered to Commissioner of Water Supply Robert Grier Monroe | Nov. 30, 1903 |
| Constitutional amendment passed exempting water-supply bonds from debt limit | Nov. 8, 1904 |
| Chapter 724 of the Laws of 1905, creating the Board of Water Supply and defining its duties and powers, signed by Governor Frank W. Higgins | Jun. 3, 1905 |
| Board of Water Supply Commissioners appointed by Mayor George B. McClellan | Jun. 9, 1905 |
| Chief Engineer J. Waldo Smith began his duties | Aug. 1, 1905 |
| Report of Board of Water Supply to Board of Estimate and Apportionment, recommending development of the Catskill Mountain watersheds, submitted | Oct. 9, 1905 |
| Plan for this development adopted by Board of Estimate and Apportionment | Oct. 27, 1905 |
| Plan filed with State authorities for approval | Nov. 3, 1905 |
| Development of watersheds of the Esopus, Rondout and Catskill creeks approved by State authorities | May 14, 1906 |
| Contract 2, the first for aqueduct construction, embracing 11 miles between Cold Spring and Hunters brook, awarded | Mar. 27, 1907 |
| First sod turned, with appropriate ceremonies, by Mayor McClellan, near Garrison | Jun. 20, 1907 |
| Maximum contractors' forces, 17,243 men, at active field work | Aug. 23, 1911 |
| Brooklyn water delivered to Queens borough through 48-inch main laid by the Board of Water Supply | May 16, 1913 |
| Storage of water in the Ashokan reservoir begun | Sep. 9, 1913 |
| Authority to develop the Schoharie watershed obtained from State authorities | Oct. 21, 1914 |
| Began filling the Kensico reservoir with Catskill water | Nov. 22, 1915 |
| Began filling the Hill View reservoir with Catskill water | Nov. 30, 1915 |
| Board of Water Supply approved amended plan for development of the Schoharie watershed | Dec. 22, 1915 |
| First delivery of Catskill water into the distribution pipes of New York City; Bronx borough supplied with Catskill water for the first time* | Dec. 27, 1915 |
| Hill View reservoir filled to full flow line for the first time | Dec. 29, 1915 |
| Board of Estimate and Apportionment adopted amended plan to develop the Schoharie watershed | Jan. 31, 1916 |
| Amended Schoharie plan filed with the State authorities for approval | Feb. 29, 1916 |
| Kensico reservoir filled to full flow line for the first time | May 23, 1916 |
| State Conservation Commission approved amended Schoharie plan | Jun. 6, 1916 |

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* Small quantities mixed with Bronx River water had been supplied to the Williamsbridge district through the Bronx conduit during the last week of November, 1915.

## Brief Chronology of the Catskill Mountain and Rondout-Delaware Water Supplies (*Continued*)

| | |
|---|---|
| Manhattan borough supplied with Catskill water for the first time | Nov. 29, 1916 |
| Water from the Ashokan reservoir passed over the spillway for the first time | Dec. 12, 1916 |
| Brooklyn and Queens boroughs supplied with Catskill water for the first time | Jan. 22, 1917 |
| Richmond borough supplied with Catskill water for the first time; began filling the Silver Lake reservoir with Catskill water | Jan. 27, 1917 |
| Silver Lake reservoir filled to full flow line for the first time | Feb. 20, 1917 |
| Maintenance of the Esopus watershed and operation of completed reservoir and aqueduct structures transferred to Department of Water Supply, Gas and Electricity | Aug. 1, 1917 |
| Civic celebration of the introduction of Catskill water into New York City | Oct. 12, 13 and 14, 1917 |
| Contract 200, for the Shandaken tunnel, the first contract for the Schoharie development, awarded | Nov. 9, 1917 |
| Board of Estimate and Apportionment adopted resolution requesting the Board of Water Supply to undertake studies for an additional supply of water for New York City | Jun. 17, 1921 |
| Schoharie Creek water delivered through the Shandaken tunnel for the first time | Feb. 9, 1924 |
| Plan for City Tunnel No. 2 submitted to Board of Estimate and Apportionment for approval | Dec. 30, 1924 |
| Full capacity of the Catskill aqueduct made available for the first time by placing in operation the last pipe-line at the steel-pipe siphons | Jan. 7, 1925 |
| Storage of water in the Schoharie reservoir begun | Jul. 24, 1926 |
| Board of Estimate and Apportionment approved policy of Board of Water Supply with respect to sewage disposal in villages on the Schoharie watershed | Dec. 9, 1926 |
| Plan for City Tunnel No. 2 adopted by Board of Estimate and Apportionment | Mar. 10, 1927 |
| Plan for City Tunnel No. 2 filed with State authorities for approval. | May 18, 1927 |
| Plan for City Tunnel No. 2 approved by State authorities | Jun. 15, 1927 |
| Maintenance and operation of the Shandaken tunnel transferred to Department of Water Supply, Gas and Electricity | Jul. 1, 1927 |
| Plan for development of the Rondout creek and tributaries of the Delaware river submitted to Board of Estimate and Apportionment for approval | Jul. 27, 1927 |
| Authority to develop water supply from the Catskill creek and its tributaries and Kaaterskill creek, with aqueduct from the Catskill creek to the Ashokan reservoir, rescinded by Water Power and Control Commission | Sep. 26, 1927 |
| Schoharie reservoir filled to full flow line for the first time | Oct. 19, 1927 |
| Maintenance and operation of the Schoharie reservoir transferred to Department of Water Supply, Gas and Electricity | Jan. 1, 1928 |

## BRIEF CHRONOLOGY OF THE CATSKILL MOUNTAIN AND RONDOUT-DELAWARE WATER SUPPLIES (*Continued*)

| | |
|---|---|
| Plan for development of the Rondout creek and tributaries of the Delaware river adopted and approved by Board of Estimate and Apportionment | Jan. 12, 1928 |
| Plan for development of the Rondout creek and tributaries of the Delaware river filed with Water Power and Control Commission for approval | Jan. 19, 1928 |
| State of New Jersey started action in United States Supreme Court in the Delaware River Case to prevent diversion of waters of Delaware River tributaries | May 13, 1929 |
| Plan for development of the Rondout creek and tributaries of the Delaware river approved by Water Power and Control Commission | May 25, 1929 |
| Charles N. Burch appointed Special Master in the Delaware River Case | Jan. 27, 1930 |
| Development of the Schoharie and Esopus creeks completed (with transfer of Grand Gorge sewerage system and future sewer construction to Department of Water Supply, Gas and Electricity) | Aug. 1, 1930 |
| Report of the Special Master (dated February 2, 1931) in the Delaware River Case ordered filed | Feb. 25, 1931 |
| $50,000,000 for construction of Kensico-Hill View tunnel of Rondout-Delaware project authorized by Board of Estimate and Apportionment | Apr. 17, 1931 |
| Opinion of the United States Supreme Court in the Delaware River Case rendered | May 4, 1931 |
| Decree in the Delaware River Case entered | May 25, 1931 |
| Work to the value of $2,350,000 done in one month on City Tunnel No. 2 and equipment contracts (maximum contractors' earnings for one month) | June, 1931 |
| Prior authorizations of funds reduced by Board of Estimate and Apportionment, for City Tunnel No. 2 from $64,000,000 to $57,000,000 and for Kensico-Hill View tunnel from $50,000,000 to $1,000,000, preventing the awarding of additional contracts for either project | Apr. 1, 1932 |
| Application made by The City of New York to the Federal Emergency Administration of Public Works for a loan and grant of $1,000,000 for the completion of City Tunnel No. 2 | Sep. 28, 1933 |
| Loan and grant of $1,000,000 for completion of City Tunnel No. 2 authorized by Federal Emergency Administration of Public Works | Dec. 28, 1933 |
| Loan Agreement between The City of New York and United States of America executed | May 17, 1934 |
| First contracts for mechanical equipment for City Tunnel No. 2 awarded under P.W.A. loan and grant | Jun. 20, 1934 |

AVERY CLASSICS

## BRIEF CHRONOLOGY OF THE CATSKILL MOUNTAIN AND RONDOUT-DELAWARE WATER SUPPLIES (*Concluded*)

| | |
|---|---|
| Capital Outlay Budget for 1936, including estimate of $20,000,000 for Delaware project, approved by Board of Estimate and Apportionment | Mar. 30, 1936 |
| First delivery of water from City Tunnel No. 2; water delivered into Brooklyn distribution system | Mar. 31, 1936 |

## BOARD OF WATER SUPPLY FORCES

| BUREAU | APRIL 1, 1936 | MAXIMUM AT VARIOUS DATES |
|---|---|---|
| Commissioners | 2 | 3 |
| Administration bureau and Bureau of Claims | 21 | 66 |
| Police bureau | 10 | 387 |
| Engineering bureau: | | |
| Chief Engineer and staff | 5 | 13 |
| Headquarters department | 75 | 260 |
| Watershed department | 29 | 38 |
| City Aqueduct department | 67 | 209 |
| Reservoir department | 0 | 236 |
| Northern Aqueduct department | 0 | 630 |
| Southern Aqueduct department | 0 | 318 |
| Aqueduct department | 0 | 95 |
| Total, Engineering bureau | 176 | |
| Total, Board of Water Supply | 209 | |
| Engineering bureau: maximum force, on June 21, 1911 | | 1,348 |
| Maximum total force of the Board, on June 21, 1911 | | 1,757 |

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